Summary of OSRIN Projects – December 2014 Update

Oil Sands Research and Information Network
School of Energy and the Environment
University of Alberta

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Oil Sands Research and Information Network

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OSRIN is a university-based, independent organization that compiles, interprets and analyses available information about returning landscapes and water impacted by oil sands mining to a natural state and provides knowledge to those who can use it to drive breakthrough improvements in reclamation regulations and practices. OSRIN is a project of the University of Alberta's School of Energy and the Environment (SEE). OSRIN was launched with a start-up grant of $4.5 million from Alberta Environment and a $250,000 grant from the Canada School of Energy and Environment Ltd.

OSRIN provides:

- **Governments** with the independent, objective, credible information and analysis required to put appropriate regulatory and policy frameworks in place
- **Media, opinion leaders and the general public** with the facts about oil sands development, its environmental and social impacts, and landscape/water reclamation activities – so that public dialogue and policy is informed by solid evidence
- **Industry** with ready access to an integrated view of research that will help them make and execute environmental management plans – a view that crosses disciplines and organizational boundaries

OSRIN recognizes that much research has been done in these areas by a variety of players over 40 years of oil sands development. OSRIN synthesizes this collective knowledge and presents it in a form that allows others to use it to solve pressing problems. Where we identify knowledge gaps, we seek research partners to help fill them.

Citation

This report may be cited as:

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Copies of this report may be obtained from OSRIN at osrin@ualberta.ca or through the OSRIN website at http://www.osrin.ualberta.ca or directly from the University of Alberta's Education & Research Archive at http://hdl.handle.net/10402/era.17507.

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REPORT SUMMARY

The Oil Sands Research and Information Network (OSRIN) has identified six program areas in which it is funding work. Within each program area, we are funding projects to scope out the state of knowledge, identify knowledge gaps, and develop products and recommendations to fill the gaps.

- Tailings Reclamation
- Regional Landscape Reclamation
- Monitoring Ecosystem Impacts
- Increasing Awareness
- Social, Economic and Regulatory
- Strategic Design

This report provides a list of active and completed projects under each of these program areas.

ACKNOWLEDGEMENTS

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1 INTRODUCTION

This report provides an overview of each of OSRIN's research program areas. The following sections list OSRIN's Active and Completed projects by Program:

- Tailings Reclamation
- Regional Landscape Reclamation
- Monitoring Ecosystem Impacts
- Increasing Awareness
- Social, Economic and Regulatory
- Strategic Design

Projects in each sub-section (Active or Completed) are listed in alphabetical order (Note: Project titles may differ from the ultimate research report title). A short project outline is provided for Active projects or Completed projects where no final report was produced. The report citation and Report Summary are provided for Completed projects that produced a report.

Each section of the report begins with a short description of the Program objectives and a table showing Active and Completed projects with hyperlinks to the appropriate project description. At the end of each project description is a hyperlink that will take you back to the Program table to make it easier to select specific projects of interest.

In addition to research projects and related reports, OSRIN has produced staff reports including a Glossary, Annual reports, funding guidelines and report writing guidelines. These may be found at the end of this document.

1.1 What's New

The following additions or changes have been made since the last edition:

- Completed Projects
  - A Design-of-Experiment Approach to Optimize the Methylene Blue Titration Method for Oil Sands Tailings Clay Activity – Dr. Haneef Mian, NAIT Applied Research Center for Oil Sands Sustainability
  - A Framework for Wildlife Habitat Design for Oil Sands Mine Reclamation: Building Wildlife Communities from the Bottom Up – Dr. Brian Eaton, Alberta Innovates – Technology Futures
  - A Tool for Adaptation Decision-Making in Oil Sands Reclamation Under Risk of Climate Change – Dr. Clive Welham, University of British Columbia
  - Characterizing the Organic Composition of Snow and Surface Water Across the Athabasca Region – Phase 2 – Dr. Jean Birks, Alberta Innovates – Technology Futures
  - Community Structure and Bio-Prospecting in Oil Sands Tailings Ponds – Dr. Joel Dacks, University of Alberta
  - Designer Biochar-Coke Mixtures to Remove Naphthenic Acids from Oil Sands Process-affected Water (OSPW) – Dr. Daniel Alessi, University of Alberta

- Development of a Novel Engineered Bioprocess for Oil Sands Tailings Fines/Bitumen/Water Separation – Dr. Mohamed Gamal El-Din, University of Alberta
- Evaluating Use of Biochar for Oil Sands Reclamation – Dr. Derek MacKenzie, University of Alberta
- Expedited Oil Sands Tailings Consolidation Through Microbial Induced Calcite Precipitation – Dr. Yang Liu, University of Alberta
- Launch of Knowledge Translation Program for the Proposed Alberta Centre for Reclamation and Restoration Ecology (ACRRE) – Dr. Ellen Macdonald, University of Alberta
- Metrics for Assessing Fisheries Productivity of Oil Sands Compensation Lakes – Dr. Mark Poesch, University of Alberta
- Modeling and Assessing the Impact of Oil Sands Contaminants on Aquatic Food Webs – Dr. Mark Lewis, University of Alberta
- Oil Sands Rules, Tools and Capacity: Are we Ready for Upcoming Challenges? – Oil Sands Research and Information Network
- Review of Alternative Seed Packaging and Delivery Systems for Oil Sands Reclamation – Dr. Amanda Schoonmaker, Northern Alberta Institute of Technology
- Silicon Nanoparticle Membranes for Photocatalytic Oil Sands Process Water Treatment – Dr. Johnathan Veinot, University of Alberta
- Soil Microbiology as an Index of Oil Sands Reclamation Success – Dr. Sylvie Mercier Quideau, University of Alberta
- Standard Operating Procedures and Physical Properties of Oil Sands Naphthenic Acids – Dr. Haneef Mian, NAIT Applied Research Center for Oil Sands Sustainability
- Survey of Oil Sands Environmental Management Research and Information Needs – Oil Sands Research and Information Network
- Wild Plant and Soil Sampling in Support of Oil Sands Contaminant Load Assessment – Dr. Cindy Jardine, University of Alberta

2 TAILINGS RECLAMATION PROGRAM

This program seeks to identify challenges that must be addressed in accelerating the reclamation of tailings ponds and disposal areas and to catalyze necessary R&D efforts to resolve them.

Challenges for tailings reclamation include

- Accelerating the dewatering of fine tailings
- Treatment of process affected water either for environmental release for recycling or reuse either within the mining operation or in in-situ operations
- Reclamation of dewatered fine tailings
- Managing release of gases, such as H_2S or CH_4, during tailings pond reclamation

Project	Researcher
Completed Projects	
2013 Tailings Technology Development and Commercialization Workshop	Dr. Haneef Mian, NAIT
A Design-of-Experiment Approach to Optimize the Methylene Blue Titration Method for Oil Sands Tailings Clay Activity	Dr. Haneef Mian, NAIT Applied Research Center for Oil Sands Sustainability
Application of Forward Osmosis Membrane Technology for Oil Sands Process-Affected Water Desalination	Dr. Yang Liu, University of Alberta
Benign By Design: Engineered Si Nanoparticles for Oil Sands Process Water Contaminant Remediation	Dr. Jonathan Veinot, University of Alberta
Catalogue of Analytical Methods for Naphthenic Acids	Dr. Haneef Mian, NAIT
Community Structure and Bio-Prospecting in Oil Sands Tailings Ponds	Dr. Joel Dacks, University of Alberta
Designer Biochar-Coke Mixtures to Remove Naphthenic Acids from Oil Sands Process-affected Water (OSPW)	Dr. Daniel Alessi, University of Alberta
Development of a Novel Engineered Bioprocess for Oil Sands Tailings Fines/Bitumen/Water Separation	Dr. Mohamed Gamal El-Din, University of Alberta
Development of Silicon-based Optofluidic Sensors for Environmental Monitoring	Dr. Ray DeCorby, University of Alberta
Engineered Biological Processes to Accelerate Oil Sands Tailings Consolidation and Improve Reuse Water Quality	Dr. Tong Yu, University of Alberta
Expedited Oil Sands Tailings Consolidation Through Microbial Induced Calcite Precipitation	Dr. Yang Liu, University of Alberta
In-Situ Tailings Ozonation: A Combined Tailings Consolidation and Remediation Process	Dr. Yang Liu, University of Alberta
Mining Clean Bitumen Technology Action Plan (CBTAB)	Petroleum Technology Alliance Canada (PTAC)
Quantitative Characterization of Air Pollutant Emissions from Oil Sands Tailings Ponds: Phase 1 Review and Assessment of Air Pollutant Measurement Technologies	Dr. Zaher Hashisho, University of Alberta
Reclamation of Dewatered Fine Tailings	Kevin Biggar, BGC Engineering
Silicon Nanoparticle Membranes for Photocatalytic Oil Sands Process Water Treatment	Dr. Johnathan Veinot, University of Alberta
Standard Operating Procedures and Physical Properties of Oil Sands Naphthenic Acids	Dr. Haneef Mian, NAIT Applied Research Center for Oil Sands Sustainability
Synthesis of Toxicological Behavior of Oil Sands Process-Affected Water Constituents	Dr. Mohamed Gamal El-Din, University of Alberta
Tailings Dewatering Technology Review	Kevin Biggar, BGC Engineering

Project	Researcher
Tailings Water Management Project	Chris Godwalt, Alberta WaterSMART

2.1 Completed Projects

2.1.1 *2013 Tailings Technology Development and Commercialization Workshop – Dr. Haneef Mian, NAIT*

Report: Mian, H., N. Fassina, A. Mukherjee, A. Fair and C.B. Powter, 2013. Summary of 2013 Tailings Technology Development and Commercialization Workshop. OSRIN Report No. TR-32. 69 pp. http://hdl.handle.net/10402/era.31012

Abstract: NAIT-CGCE, NAIT School of Sustainable Building and Environmental Management, and the NAIT JR Shaw School of Business, in collaboration with COSIA, AIEES, and the Oil Sands Research and Information Network (OSRIN), held a technology innovation workshop on March 19, 2013 at the NAIT campus to open the dialogue between oil sands industry, academia, research and development organizations, and third-party innovators. The workshop, titled 2013 Tailings Technology Development and Commercialization: Big Ideas from Small Places, was attended by approximately 130 people from SMEs, government, industry and academia.

The following common themes arose during the presentations:

- There is considerable public scrutiny and concern about oil sands tailings-related environmental challenges
- Technology development and deployment is key to solving the tailings challenge in a sustainable manner
- There is no single technology solution for tailings disposal– a suite of technologies will be required
- For a technology to be considered suitable it must provide net environmental benefits (e.g., must be evaluated in the context of impacts on solids, liquids, GHG) and be economic (i.e., a systems perspective)
- Technologies must be deployed more quickly than in the past
- There is a need for an entity or organization that can provide a bridge between SMEs, third-party technology developers, and the oil sands companies

The workshop was a first step towards tailings technology development and commercialization. More events may be planned, some specifically focused on bringing the technology developers together and understanding their technologies. The 2nd Tailings Technology and Development Commercialization Workshop will be planned for 2014 in collaboration with all the partners. There may be an opportunity to share some results on SME and third-party vendor technologies within the 2014 workshop.

[Return to Tailings Reclamation project list](#)

2.1.2 *A Design-of-Experiment Approach to Optimize the Methylene Blue Titration Method for Oil Sands Tailings Clay Activity – Dr. Haneef Mian, NAIT Applied Research Center for Oil Sands Sustainability*

Report: Currie, R., S. Bansal, I. Khan and H. Mian, 2014. An Investigation of the Methylene Blue Titration Method for Clay Activity of Oil Sands Samples. OSRIN Report No. TR-60. 50 pp. http://hdl.handle.net/10402/era.40164

Abstract: The purpose of this report is to use a design of experiment (DOE) approach to examine the main factors affecting the determination of methylene blue index (MBI) values for oil sands samples. The methylene blue titration of clays has become a principle tool to assess extraction efficiency of oil sand ores and as a tool to assess the properties of the various tailings streams.

The report uses a Plackett-Burman (PB) DOE approach which is designed to screen a method for the principle factors affecting the test result. It does not reveal interaction between factors that could affect the significance of a main effect in the study. The purpose of the PB DOE screen is to help identify the main effects so that a more complete full factorial DOE can be implemented. A full factorial DOE allows more than two procedures/conditions or levels for each of the main effects identified by a screening DOE. This enables the conditions and procedures for specific factors in a test method to be adjusted simultaneously as other factors are varied. Thus interactions that could affect test results are accounted for which ensures that the final test method exhibits ruggedness and is capable of generating reliable data with good precision.

This report is the initial phase in the development of a rugged and robust method for methylene blue (MB) determinations. A principle requirement of the method is the dispersion of the clay samples to ensure methylene blue is capable of complete cation exchange with the clay. A 12-factor PB DOE investigated two mature fine tailings (MFT) samples for the effects of bicarbonate, basic pH adjustment, peroxide treatment, sonication, stirring, soaking, heating and Dean and Stark sample cleaning on dispersion procedures. If the number of procedures needed to disperse the clays can be minimized, without affecting the reliability of the MBI results, the method is easier to perform in a timely manner. Included in the 12-factor PB DOE was an assessment of the effects of acidic pH adjustment, preceding the titration, and variations in filter paper porosity and optional endpoint detection procedures during the titration.

A 7-factor PB DOE, using both normal and folded designs, was conducted to confirm features of the 12-factor PB DOE. The main effects studied were peroxide treatment, bicarbonate, basic pH adjustment, stirring at both room temperature and heating at 60˚C, sonication and variation in endpoint detection procedures. The folded design was to help minimize the effects of confounding or aliasing of the data where main effects can be influenced by interactions between main effect components. When this occurs a main effect may be viewed as significant when in fact it is not.

The study emphasizes the importance of basic pH and sonication to enhance dispersion. Peroxide treatment was shown in the PB DOE to have beneficial effects when the sample is exposed to lower sonication energies, as in a bath sonicator. However, in a mini-study using a probe sonicator, where the energy generated is greater, peroxide was not found to be essential in aiding dispersion as evident by consistent MBI values even when peroxide was omitted. The importance of acidifying the dispersed sample before titration is also emphasized from the PB DOE studies.

The goal of this work is to ultimately develop an automated procedure for MBI determinations. A major challenge is to provide a more objective means of identifying the endpoint of the MB titration. The report proposes a more objective non-visual endpoint based on the current halo procedure. To this end the effect of varying filter paper porosity as well as a comparison of subjective and objective endpoint detection procedures were included in the DOE. Alternative endpoint detection procedures focused on the use of spectroscopy. A spectroscopy procedure which measured changes in the aqueous forms of MB during the titration was included in the 12-factor PB DOE.

The report also discusses an innovative use of fibre optic visible spectroscopy to monitor the spectra of clay-MB interactions during the MB titration. The ability to assess whether the MB is interacting on the external or interlamellar surface of clays can enhance the information about the properties of clays in different sample types. This approach is very attractive since much more detail can be mined from the titration data than simply MBI values. This may dramatically improve the characterization of ores and tailings streams and improve process decisions regarding suitable ores for extraction and optional tailings treatments.

Finally an attempt to use NMR as a tool to monitor the titration and provide additional insight into the properties of the oil sands samples being titrated with MB is reported. Although NMR is capable of observing methylene blue in an aqueous media, and could be used similar to the spectroscopy method in the 12-factor PB DOE, it is incapable of detecting MB when the clays were also present.

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2.1.3 *Application of Forward Osmosis Membrane Technology for Oil Sands Process-Affected Water Desalination – Dr. Yang Liu, University of Alberta*

Report: Jiang, Y. and Y. Liu, 2014. Application of Forward Osmosis Membrane Technology for Oil Sands Process-Affected Water Desalination. OSRIN Report No. TR-51. 27 pp. http://hdl.handle.net/10402/era.39855

Abstract: The extraction process used to obtain bitumen from the oil sands produces large volumes of oil sands process-affected water (OSPW). As a newly emerging desalination technology, forward osmosis (FO) has shown great promise in saving electrical power requirements, increasing water recovery, and minimizing brine discharge. With the support of this funding, a treatment system was constructed using a cellulose triacetate (CTA) forward osmosis membrane to test the feasibility of OSPW desalination and contaminant removal. The

forward osmosis systems were optimized using different types and concentrations of draw solution. The forward osmosis system using 4M NH_4HCO_3 as a draw solution achieved 85% water recovery from OSPW, and 80% to 100% contaminant rejection for most metals and ions.

A water backwash cleaning method was applied to clean the fouled membrane, and the cleaned membrane achieved 77% water recovery, a performance comparable to that of new forward osmosis membranes. This suggests that the membrane fouling was reversible.

The forward osmosis system developed in this project provides a novel and energy efficient strategy to remediate the tailings waters generated by oil sands bitumen extraction and processing.

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2.1.4 *Benign By Design: Engineered Si Nanoparticles for Oil Sands Process Water Contaminant Remediation – Dr. Jonathan Veinot, University of Alberta*

This project was co-funded with the Canada School of Energy and Environment Ltd.

Report: Iqbal, M., T.K. Purkait, J.G.C. Veinot and G.G. Goss, 2013. Benign-by-Design: Synthesis of Engineered Silicon Nanoparticles and their Application to Oil Sands Water Contaminant Remediation. OSRIN Report No. TR-42. 30 pp. http://hdl.handle.net/10402/era.37308

Abstract: Oil sands are naturally occurring mixtures of sand or clay, water, fine silts, and bitumen. The oil sands extraction process consumes large volumes of water (i.e., *ca.* 3 barrels of fresh water for every 1 barrel of oil). Following the extraction of bitumen from the oil sands, a tailings slurry is produced that consists of oil sands process-affected water (OSPW), sand, silt, clay particles and trace quantities of unrecovered bitumen. This slurry is hydraulically transported to large containment facilities (i.e., open tailings ponds) that, in Alberta, currently occupy approximately 130 km^2 with 200 million litres of mature fine tailings produced each day. These vast storage facilities pose a risk to the environment, wildlife, and society.

There are many candidate technologies that could be applied to the treatment of OSPW. Advanced oxidation processes (AOPs) are particularly useful for degrading biologically toxic or non-degradable materials such as aromatics, pesticides, petroleum constituents, and volatile organic compounds in wastewater.

In this report, we investigate the use of advanced oxidation processes via photocatalysts based on nanoparticles. Silicon nanoparticles were specifically engineered for water remediation by making them water soluble and more potent towards contaminant removal. Si nanoparticles of different sizes and morphologies were investigated for model contaminant (methanol) removal in the presence of UV light. A medium pressure UV lamp was used for the purpose. Control experiments were also performed to ascertain the extent of remediation by the Si nanoparticles. Effect of methanol concentration, nanoparticle concentration and exposure time of UV were systematically studied to optimize the remediation parameters. Moreover, a cost effective and high yielding synthetic protocol was also developed for large scale synthesis of Si nanoparticles

which is crucial for scale up. Quantum yield calculations were performed on different Si nanoparticles and compared with titanium dioxide (TiO_2), the most commonly proposed nanoparticle system.

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2.1.5 *Catalogue of Analytical Methods for Naphthenic Acids – Dr. Haneef Mian, NAIT*

Report: Zhao, B., R. Currie and H. Mian, 2012. Catalogue of Analytical Methods for Naphthenic Acids Related to Oil Sands Operations. OSRIN Report No. TR-21. 65 pp. http://hdl.handle.net/10402/era.26792

Abstract: The purpose of this report is to identify challenges in analyzing naphthenic acids (NAs) associated with oil sands process water (OSPW). Naphthenic acids are present naturally in oil sands bitumen and have the classical formula $C_nH_{2n+Z}O_2$. Within this formula n represents the carbon number and Z is an even, negative integer corresponding to hydrogen deficiency mainly due to ring formation in the structure. Thus the absolute value of Z divided by 2 gives the number of the rings in the compounds. A Z-value of 0 means acyclic acids, which are believed to be highly branched rather than linear natural fatty acids. A Z-value of -2 represents monocyclic NAs; -4 represents bicyclic and so on. The Z-value may also include unsaturation in the chemical structure. The generality of the formula allows for a vast array of isomers for each value of n and Z. The challenge in analyzing NAs from OSPW is that microbial activity alters the structure of classical naphthenic acids creating a large number of compounds that are labeled as naphthenic acids but differ from the $C_nH_{2n+Z}O_2$ general formula. This increased number of compounds elevates the demands on the analytical methods used to characterize these compounds obtained from OSPW. In this report, issues affecting both qualitative and quantitative data from a variety of analytical methods will be reviewed to generate an awareness of the challenges faced by laboratories conducting NA determinations. The report also highlights the issues of naming these compounds "naphthenic acids" since many of the compounds being extracted from OSPW do not conform to the classical NA formula.

The method chosen has a significant effect on the interpretation of the analytical data. Analytical results are dependent on sampling, extraction and clean-up techniques. The report examines various approaches used to prepare samples for analysis based on the following themes: sampling tools and techniques, sample preservation and transport, extraction, and clean-up methods. There are numerous analytical instruments currently being used in the analysis of NAs. Within the field of spectroscopy Fourier Transform Infrared Spectroscopy (FTIR) has been used and is often considered the reference method for quantitative assessment of NAs in OSPW. Both, UV-Vis and fluorescence spectroscopy, and more recently Synchronous Fluorescence Spectroscopy (SFS) have been applied to studies of NAs in OSPW. Each of these methods are limited in the information that can be provided, however, they have value in assessing the types and possible sources of NAs being evaluated in a sample.

Major advancements in the analysis of NAs are being accomplished using the power of chromatography to attain a partial separation of thousands of compounds found in a NA extract

and mass spectrometry (MS) for their detection. Early methods of analysis using unit mass resolution MS have created problems in properly assessing NAs present in OSPW. This has led to the overestimation of NA concentrations in OSPW. Similar problems have been encountered with FTIR. Misclassification and identification of false positives has been another issue plaguing early adopters of these analytical methods. Fortunately, new analytical tools are being developed which enable high resolution mass spectrometry (HRMS) to be performed enabling these errors in classification to be partially rectified. Although many efforts have been made in the development of analytical methods, no rugged routine method that can separate, identify, and quantify the individual components of NA mixtures has been achieved to date. This review will provide an overview of methods currently used for the analysis of NA class of compounds including sampling, sample preservation, sample transport, extraction and clean-up, analytical techniques, and future needs, with a major focus on NAs from OSPW.

No method currently exists that is capable of identifying all isomers of NAs. Without this capability it is impossible to clearly assess the toxicity of individual "naphthenic acids" encountered in OSPW. Additionally it makes it difficult to fully understand the potential for biodegradation and remediation of NAs in fluid tailings or their long term impacts in the reclaimed landscape.

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2.1.6 *Community Structure and Bio-Prospecting in Oil Sands Tailings Ponds – Dr. Joel Dacks, University of Alberta*

Report: Aguilar, M., E. Glücksman, D. Bass and J.B. Dacks, 2014. Next Generation Sequencing of Protists as a Measure of Microbial Community in Oil Sands Tailings Ponds: Amplicon Versus Metagenomic Approaches. OSRIN Report No. TR-56. 24 pp. http://hdl.handle.net/10402/era.40100

Abstract: The Alberta oil sands provide a major benefit to the province as an economic driver. At the same time, their responsible exploitation, particularly in mitigating the environmental impact of oil extraction stands as a significant challenge to be addressed. One of the most contentious aspects is the reclamation of tailings ponds, vast reservoirs of post-processing water and solids mixed with a variety of industrial compounds. Microbiological processes from bacteria and archaea have been previously shown to be at play in the tailings ponds and are factored into plans for their reclamation. However, the impact of microbial eukaryotes, known in all other environments to play a role in the food web, has been relatively poorly addressed. This will be important to know, particularly in light of end pit lake plans for reclamation moving forward.

To better understand the microbial communities in the tailings ponds for improved reclamation planning, we have begun using next generation sequencing (NGS) methods to understand the microbial eukaryotic communities present in tailings. We also compare results from two different NGS strategies, metagenomic versus amplicon based, to assess a productive strategy for analyses going forward.

Metagenomic data sequenced using the Illumina platform from a tailings sample were obtained via the Hydrocarbon Metagenomics project. Amplicon data were generated in the lab from extracted genomic DNA from the same environmental sample that generated the metagenome data and sequenced using the Illumina platform. Informatic analyses of these datasets were run to obtain ecological measures (rank abundances, diversity indices, taxonomic affiliation).

Both the metagenomic and amplicon datasets confirmed the presence of a diverse community of microbial eukaryotes in the tailings. The overall taxonomic affiliations of the sequences were broadly consistent. However, the amplicon-based study gave vastly more data than the metagenomic one, showing a large additional set of low abundance organisms present in the sample.

The community of microbial eukaryotes in the tailings pond is real, non-trivial and diverse. The breadth of the community within different ponds, at different spatial distributions and seasons should be explored to better understand the extent of what is present and how it changes periodically through the year so as to better plan reclamation efforts.

The amplicon-based analysis gave ~1,600x more data and revealed a much more complex picture of eukaryotic diversity. While metagenomic approaches give a broader picture of all genes from all microbes in the environment, for the specific question of assessing eukaryotic diversity an amplicon based approach is recommended at the present time.

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2.1.7 *Designer Biochar-Coke Mixtures to Remove Naphthenic Acids from Oil Sands Process-affected Water (OSPW) – Dr. Daniel Alessi, University of Alberta*

Report: Alessi, D.S., M.S. Alam and M.C. Kohler, 2014. Designer Biochar-Coke Mixtures to Remove Naphthenic Acids from Oil Sands Process-Affected Water (OSPW). OSRIN Report No. TR-57. 38 pp. http://hdl.handle.net/10402/era.40122

Abstract: The objective of this 6-month pilot experimental study was to test the ability of biochars derived from Alberta biomass and an oil sands petroleum coke to remove selected organic acids from water. To this end, we selected one biochar produced from wheat straw and made by the Alberta Biochar Initiative, and an oil sands petroleum coke produced by Syncrude Canada Ltd. Both materials were extensively characterized for morphology, surface area, surface reactivity, porosity, and composition. Following this characterization, two model organic species, lauric acid and 1-methylcyclohexanecarboxylic acid, were adsorbed to the biochar, coke, and mixtures of the two, at varying ratios.

Our results indicate that the biochar used in this study is a significantly more efficient sorbent for removal of both organic acids tested from water than is the petroleum coke. The petroleum coke was found to remove a lower but significant amount of each organic acid from solution. The use of petroleum coke as a sorbent will likely depend on environmental risks such as the leaching of sulphur, vanadium, and nickel from the material, and its cost relative to the production and delivery of biochar to oil sands facilities.

Future studies should focus on assessing the total sorption capacity of each sorbent in flow-through reactor experiments, and determining whether combined biochar + petroleum coke systems may be efficient at removing both organic contaminants and metals from oil sands process-affected water.

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2.1.8 *Development of a Novel Engineered Bioprocess for Oil Sands Tailings Fines/Bitumen/Water Separation – Dr. Mohamed Gamal El-Din, University of Alberta*

Report: McPhedran, K., M.S. Islam and M. Gamal El-Din, 2014. Development of a Novel Engineered Bioprocess for Oil Sands Process-Affected Water and Tailings Fines/Bitumen/Water Separation. OSRIN Report No. TR-63. 28 pp. http://hdl.handle.net/10402/era.40190

Abstract: The oil sands bitumen extraction process results in the creation of waste products including oil sands process-affected water (OSPW) and mature fine tailings (MFT). Many technologies are currently under investigation to treat these waste products that are currently contained in vast storage ponds. Biodegradation is a promising treatment method, however, the current biodegradation rates for indigenous bacteria in storage ponds are very slow and need to be enhanced for this process to be considered viable. The BioTiger™ consortium has been successfully used for the treatment of oil contaminated soils making it a potentially useful bacterial assemblage for the treatment of both OSPW and MFT.

In this study, BioTiger™ was not successful for treatment of OSPW after 24 h experiments at 8, 22 and 35 °C. Results for toxicity to *V. fischeri* were inconclusive, while there was no reduction in either the acid extractable fraction (AEF) or the naphthenic acid (NA) contents. The MFT experiments have not commenced as of yet due to the unavailability of some samples. These experiments will start in January 2015 and run for approximately four months. It is expected that the longer duration will allow the BioTiger™ to biodegrade organics in the MFT.

Although the current OSPW experiments did not produce anticipated results, further research is planned to better assess the ability of BioTiger™ to degrade OSPW organics. These experiments will include longer experimental durations, higher initial bacterial concentrations and/or amendment with easily degradable organics. These new conditions should aid the consortium to better acclimate to, and degrade, recalcitrant OSPW organics.

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2.1.9 *Development of Silicon-based Optofluidic Sensors for Environmental Monitoring – Dr. Ray DeCorby, University of Alberta*

This project was co-funded with the Canada School of Energy and Environment Ltd.

Report: De Corby, R.G., 2013. Development of Silicon-Based Optofluidic Sensors for Oil Sands Environmental Monitoring. OSRIN Report No. TR-41. 19 pp. http://hdl.handle.net/10402/era.36936

Abstract: The oil sands industry in Alberta produces large volumes of process-affected water (PAW), which is known to contain heavy metals and organic compounds (such as naphthenic acids, naphthalene, phenanthrene, pyrene, etc.) that are toxic and hazardous to the environment. The industry has an ongoing need to improve the monitoring of concentrations and breakdown of these compounds. Currently, this is mainly accomplished by collecting samples for shipment to a laboratory for analysis. Portable and ideally distributed and real-time monitoring techniques would greatly improve efficiency and the base of knowledge with respect to these environmental concerns.

The principal aim of the project was to develop a prototype lab-on-a-chip (LOC) based sensor for optical detection of target molecules in PAW using spectrally resolved fluorescence detection. The proposed sensor would offer a high level of integration between the fluidic and optical components, potentially reducing the cost and complexity of the overall system while also improving the performance (sensitivity, signal to noise ratio (SNR), alignment tolerance, etc.). In the long term, such miniaturized sensors hold promise as low-cost, highly distributed environmental monitoring devices.

Most of the primary milestones of the project were successfully completed, as follows:

1. A silicon-based air-core waveguide technology was developed and optimized for the ultraviolet-visible wavelength band of interest. These waveguides employ low-loss TiO_2/SiO_2 Bragg reflectors deposited by sputtering deposition at the U of A nanoFab.
2. Tapered air-core waveguides were assembled and tested as visible-band micro-spectrometers. These micro-spectrometers provide resolution on the order of 1 nm over a 100 nm operational band (e.g., wavelengths in the 500 to 600 nm range), and offer compelling advantages for lab-on-a-chip and optofluidic microsystems.
3. Prototype sensing systems were developed, by combining the aforementioned micro-spectrometers with PDMS-based microfluidics. Fluorescence spectroscopy was successfully demonstrated for commercial dyes with fluorescence bands in the ~500 to 600 nm wavelength range.

At the time of writing, ongoing work is aimed at translating the operational band of these sensors to the ~400 to 500 nm wavelength range. This effort has been delayed by processing difficulties, but is expected to reach a successful conclusion in summer 2013. Further work is aimed at extending the operational range of the micro-spectrometers (e.g., 400 to 650 nm), by using more sophisticated multilayer designs. We hope that this work will enable the detection of native fluorescence from hydrocarbon molecules, including the multiplexed detection of multiple species, and intend to pursue this objective in the coming months.

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2.1.10 *Engineered Biological Processes to Accelerate Oil Sands Tailings Consolidation and Improve Reuse Water Quality – Dr. Tong Yu, University of Alberta*

Report: Zhu, L., M. Yu, L. Delgado Chávez, A. Ulrich and T. Yu, 2014. Review of Bioreactor Designs Applicable to Oil Sands Process-Affected Water Treatment. OSRIN Report No. TR-52. 39 pp. http://hdl.handle.net/10402/era.39903

Abstract: The objectives of our research program were to: (1) study biological activities in oil sands mature fine tailings and oil sands process-affected water, (2) develop microbial biofilm seed to support engineered biological processes with enhancement measures, and (3) review available bioreactor technologies and select bioreactors for continuous operation in the next phase of the study. This report focuses on the literature review. A summary of the results of two M.Sc. theses focusing on objectives 1 and 2 of the research program are provided as an appendix to this report. Further information is available in the theses.

We reviewed 89 papers (from 1980 to 2014) covering eight types of bioreactors with an emphasis on their performance in treating recalcitrant industrial wastewaters. Three types of reactors were selected for further analysis because they have been successfully developed and used for removal of refractory organic compounds from industrial wastewaters. They are moving-bed biofilm reactor, membrane bioreactor, and up-flow anaerobic sludge blanket reactor. The literature review confirmed our initial understanding that in biodegradation of recalcitrant organic compounds, a successful strategy is to first employ an anaerobic bioreactor to break down primarily large molecular organic compounds, increasing their biodegradability, and then use an aerobic bioreactor for the biodegradable organic compounds. Biofilm, or aggregated microbial growth with mixed microbial populations including both anaerobic and aerobic species, is more effective in biodegradation of recalcitrant organic compounds and more resilient to survive in harsh environmental conditions.

Based on the literature search, we have selected moving-bed biofilm reactor as the first reactor type for continuous operation. This type of bioreactor can support biofilm growth, can be operated under both anaerobic and aerobic conditions, has been tested on a variety of wastewaters, and has the advantages of low cost and ease of operation. The bioreactor system has been designed, fabricated, installed and tested. It is ready for continuous operation, pending funding for the next phase of continuous bioreactor operation. The selection of a second type of bioreactor with different configuration and superior performance is in progress.

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2.1.11 *Expedited Oil Sands Tailings Consolidation Through Microbial Induced Calcite Precipitation – Dr. Yang Liu, University of Alberta*

Report: Liang, J., Z. Guo, L. Deng and Y. Liu, 2014. MFT Consolidation Through Microbial Induced Calcium Carbonate Precipitation. OSRIN Report No. TR-66. 31 pp. http://hdl.handle.net/10402/era.40330

Abstract: The accumulation of mature fine tailings (MFT) in tailings ponds has been a concern of the oil sands industry and regulators for decades. Previous studies and current practices for fine tailings consolidation focus on the addition of inorganic and organic additives to reduce MFT production and accumulation. These treatment processes are were not sufficiently efficient in reduction of fluid tailings accumulation. In addition, treatments using chemical and polymer additives do not effectively increase the solids content of the settled tailings to more than 50%, which is lower than the required level for the surface trafficability mandated in Directive 074 issued by the Energy Resources Conservation Board. The development of treatment technologies to remove the last remnants of water from the settled tailings is critical. It is desirable to develop more efficient and effective techniques for MFT consolidation to reduce the risk to wildlife and ecosystems in the surrounding area.

In this study, the performance and mechanisms of a microbial induced calcite precipitation (MICP)-assisted MFT settling and consolidation method was assessed. MFT samples of 35 wt% and 60 wt% were treated with MICP. The volume of released water, the solids content of the tailings, and the shear strength of MFT were measured to evaluate the effects of MICP on MFT consolidation. MFT initial settling curves were developed by monitoring the change of the water-solid interface position over time. To investigate the surface interaction mechanisms involved in the process, the calcium concentration of MFT release water was measured and the size and shape of MFT particles were observed by scanning electron microscopy (SEM).

The results showed that although treatment with ureolysis-driven MICP effectively accelerated diluted MFT settling, ureolysis-driven MICP had little capacity to settle solids in raw (undiluted) MFT samples using tested reagents concentrations. In terms of MFT consolidation, our results clearly showed that ureolysis-driven MICP can accelerate raw MFT consolidation, leaving compact sludge with significantly enhanced shear strength within 24 hours of the experiment. Consolidation of the settled solids and settling of the MFT slurry through ureolysis-driven MICP might be achieved through precipitation of calcite on bacteria and solid surfaces, altering surface characteristics of particulate materials, and reducing steric or electrostatic stabilizing effects among particles.

The denitrification-driven MICP did not show promising results in terms of either MFT settling or consolidation. Denitrification may require more time and/or additional nutrient addition to accelerate the denitrification process, and to settle and consolidate MFT.

Ureolysis-driven MICP provides several advantages compared to traditional chemical additives currently used or studied to accelerate MFT consolidation: (1) ureolysis-driven MICP is effective for consolidating MFT from different sources and with different surface properties; (2) although mixing is needed to introduce the bacterial culture to MFT, mixing conditions do not significant impact the effectiveness of MICP-assisted consolidation process; (3) the key sources (calcium and carbonate ions) required to expedite $CaCO_3$ precipitation and MFT settlement are readily available in tailings; (4) the required dosage of urea is much less than that of other traditional chemical additives; and, (5) $CaCO_3$ precipitation reduces the calcium concentration, potentially enhancing the quality of the recycled water.

For future research, experimental conditions for ureolysis-driven MICP can be improved by optimizing stoichiometric amounts of Ca and urea, bacterial growth conditions and nutrient levels. Field application strategies for urea and bacterial culture should be evaluated. Options for anaerobic calcite precipitation should be tested, particularly processes that utilize endogenous microorganisms. The options of combining MICP to other consolidation processes and to further improve MFT consolidation and strength should be tested and evaluated. Long-term studies on the impact of MICP assisted MFT settling and consolidation on land reclamation should be performed.

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2.1.12 *In-Situ Tailings Ozonation: A Combined Tailings Consolidation and Remediation Process – Dr. Yang Liu, University of Alberta*

This project was co-funded with the Canada School of Energy and Environment Ltd.

Report: Liang, J., F. Tumpa, L.P. Estrada, M. Gamal El-Din and Y. Liu, 2014. Ozone-Assisted Settling of Diluted Oil Sands Mature Fine Tailings: A Mechanistic Study. Oil Sands Research and Information Network, University of Alberta, School of Energy and the Environment, Edmonton, Alberta. OSRIN Report No. TR-46. 43 pp. http://hdl.handle.net/10402/era.38226

Abstract: The accumulation of mature fine tailings (MFT) in tailings ponds with very slow natural consolidation rate has been a big concern for decades. Previous studies and current practices for tailings consolidation focus on the addition of various inorganic and organic additives to reduce MFT production and accumulation. It is highly desirable to develop more efficient and effective techniques for MFT consolidation to reduce the potential environmental impacts of oil sands tailings.

In this study, the performance and mechanisms of a novel ozone-assisted MFT dewatering method were evaluated. MFT with different solid contents were ozonated for 15, 30, and 60 minutes to determine the optimal ozonation treatment conditions for MFT consolidation. The volume and turbidity of released water, and the solids content of settled sludge (i.e., solids) were measured to evaluate the performance of ozone on MFT consolidation. MFT initial settling curves were developed by monitoring the change of the water and sludge interface positions over time. To investigate the surface interaction mechanisms involved in the process, major ions of MFT release water and the surface charge of MFT fine particles were characterized. Specifically, these parameters included pH, ion concentrations, acid extractable fraction (AEF) concentration of MFT release water, zeta potentials, and surface functional groups of fine particles. Additional experiments were performed to investigate the roles of pH and ion concentrations in ozone assisted MFT consolidation.

Our results showed that ozonation treatment effectively accelerated diluted MFT particle settling at all treatment conditions tested in this study. MFT quickly settled after short (15 minute) ozonation treatment, leaving clear brown water and compact settled sludge. The volume and turbidity of release water and the solids content of settled sludge were comparable at 1 wt% MFT under different ozonation times (15, 30 and 60 minutes). At 3 wt% and 5 wt% MFT, a longer

ozonation time improved MFT settling. Therefore, we conclude that the ozonation time needed for MFT settling varied depending on the solids content of MFT suspensions.

Additional studies showed that the ozone-accelerated settling of MFT particles probably results from a change in MFT particle surface properties and the weakening of repulsive forces among fine particles through at least four mechanisms: (1) the desorption of stabilized organic matter on MFT surfaces, which reduces the steric or electrostatic stabilizing effects among fine particles; (2) the release of organic acids (such as oxalic and acetic acids) into the water, which decreases the pH of the MFT suspensions and neutralizes MFT surface charges; (3) ozone breakage of organometallic complexes in MFT, leading to the release of oxidized metal ions such as Fe^{2+}, Mn^{2+}, and Al^{3+} that can act as coagulants; and, (4) an increase in cations and carboxylic groups that facilitate the generation of metal humate complexes, leading to an accelerated precipitation of fine particles.

Compared to the chemical additives currently used or studied to accelerate MFT consolidation, ozone-based processes have several advantages: (1) The process is economical because even a low ozone dose appears to be sufficient to destabilize tailings fine particles; (2) The process is environmentally friendly because ozone decomposes rapidly; and (3) The excess ozone can decompose organic compounds in tailings and thus improve the water quality.

Despite the promise observed in the present study, a cost analysis and a life cycle analysis should be performed to determine the feasibility of this treatment process. The effectiveness of ozonation treatment for undiluted MFT settling should be evaluated. The toxicity of the release water should be evaluated to examine the environmental impact of the process. Additional research on the long-term impact of ozone-assisted MFT settling processes on MFT reclamation is also needed.

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2.1.13 *Mining Clean Bitumen Technology Action Plan (CBTAB) – Petroleum Technology Alliance Canada (PTAC)*

OSRIN supported this multi-player project to identify technology opportunities for breakthrough improvement in environmental and economic performance in oil sands development. OSRIN's primary interest is on technologies related to minimizing and managing tailings ponds. OSRIN was one of 23 investors.

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2.1.14 *Quantitative Characterization of Air Pollutant Emissions from Oil Sands Tailings Ponds: Phase 1 Review and Assessment of Air Pollutant Measurement Technologies – Dr. Zaher Hashisho, University of Alberta*

Report: Hashisho, Z., C.C. Small and G. Morshed, 2012. Review of Technologies for the Characterization and Monitoring of VOCs, Reduced Sulphur Compounds and CH_4. OSRIN Report No. TR-19. 93 pp. http://hdl.handle.net/10402/era.25522

Abstract: The overall goal of this project is to better understand the advantages and limitations of air emission pollutant characterization and monitoring techniques from area sources. This will allow for the selection of current technologies that are most suitable for measuring fugitive emissions of air pollutants from oil sands tailings ponds.

The project consists of the following tasks:

Task 1: Review concentration measurement technologies for volatile organic compounds (VOCs) reduced sulphur compounds (including H_2S), and CH_4.

Task 2: Review flux measurement technologies that are used or can be used to measure air pollutant emissions from oil sand tailing ponds.

Task 1: Review concentration measurement technologies for volatile organic compounds (VOCs), reduced sulphur compounds, and CH_4

Methodology

A review was conducted to determine the available technologies for characterizing and measuring the flux of each of the three groups of pollutants (VOCs, reduced sulphur compounds, and CH_4). The review of the technologies included the following: a short description of the technology and its operating principle; instrument sensitivity (detection limit); advantages and limitations of the technique (performance, versatility, reliability); and cost, whenever possible. Costs do not include the labour to collect samples or the costs involved in running the analyses at other laboratories, as these are variable. However, such costs should be weighed when considering the application of the different technologies. Sample collecting procedures are important as they may affect the accuracy and precision of the technologies; these techniques are generally standard and have not been focused on for this report.

Technologies for VOC Characterization

The technologies for VOC characterization were classified into conventional analytical technologies (based on laboratory and field techniques) and remote sensing monitoring technologies (based on field techniques).

The following technologies have been reviewed and assessed:

- Conventional Analytical Technologies
  - Flame Ionization Detection (FID)
  - Infrared (IR) Absorption Spectroscopy
  - Photo Ionization Detection (PID)
  - Gas Chromatography-Mass Spectrometry (GC-MS)
  - Proton-Transfer-Reaction Mass Spectrometry (PTR-MS)
  - Fourier Transform Infrared (FT-IR) Spectroscopy

- Remote Sensing Monitoring Technologies
  - Open Path Fourier Transform Infrared (OP-FTIR) Spectroscopy
  - Differential Optical Absorption Spectroscopy (DOAS)
  - Tunable Diode Laser Absorption Spectroscopy (TDLAS)
  - Differential Absorption LIDAR (DIAL)
  - Solar Occultation Flux (SOF)

Technologies for Reduced Sulphur Compound Characterization

The technologies for reduced sulphur compound characterization were classified into conventional analytical technologies (based on laboratory techniques and field techniques) and remote sensing monitoring technologies (based on field techniques).

The following technologies have been reviewed and assessed:

- Conventional Analytical Technologies
  - Flame Photometric Detection (FPD)
  - Pulsed Flame Photometric Detection (PFPD)
  - Sulphur Chemiluminescence Detection (SCD)
  - Photo Ionization Detectors (PID)
  - Ultraviolet (UV) Spectrometric Detection
- Remote Sensing Monitoring Technologies
  - Tunable Diode Laser Absorption Spectroscopy (TDLAS)
  - Image Multi-Spectral Sensing (IMSS)
  - Differential Absorption LIDAR (DIAL)
  - Open Path Fourier Transform Infrared (OP- FTIR) Spectroscopy

Technologies for CH_4 Characterization

The technologies for CH_4 characterization were classified into conventional analytical technologies (based on laboratory and field techniques) and remote sensing monitoring technologies (based on field techniques).

The following technologies have been reviewed and assessed:

- Conventional Analytical Technologies
  - Infrared (IR) Absorption
  - Mid-Infrared Polarization Spectroscopy
  - Photoacoustic Absorption Spectroscopy (PAS)

- Solid State (SS) sensor
- Wavelength Modulation Spectroscopy (WMS)

- Remote Sensing Monitoring Technologies
  - Radial Plume Mapping (RPM)
  - Differential Optical Absorption Spectroscopy (DOAS)
  - Correlation Spectroscopy (CS)
  - Airborne Natural Gas Emission Lidar (ANGEL)

Task 2: Review flux measurement technologies that are used or can be used to measure emissions from air pollutant emissions and greenhouse gases from oil sand tailing ponds.

The technologies for measuring concentration fluxes of fugitive emissions within the atmosphere were also classified into conventional analytical techniques and remote sensing monitoring technologies (all based on field techniques).

The following technologies have been reviewed and assessed:

- Conventional Analytical Techniques
  - Chamber Methods
  - Eddy Covariance (EC)
  - Eddy Accumulation and Relaxed Eddy Accumulation
  - Flux Gradient Techniques
  - Mass Balance Techniques
  - Tracer Gas Method
- Remote Sensing Monitoring Technologies
  - Solar Occultation Flux (SOF)
  - Nocturnal Boundary Layer Box Method
  - Radial Plume Mapping (RPM)

The report concludes with recommendations for technologies to use for monitoring air emissions from oil sands tailings ponds based on the following factors: spatial coverage, quantification of the pollutants, determination of emission factor, characterization of VOC speciation, and frequency of monitoring. For a variety of reasons there may not be one technology that is best suited for emission measurements across the oil sands region, and it is important to understand the different advantages and limitations of the technologies when selecting an option and interpreting the resulting data.

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2.1.15 *Reclamation of Dewatered Fine Tailings – Kevin Biggar, BGC Engineering*

Report: BGC Engineering Inc., 2010. Oil Sands Tailings Technology Review. OSRIN Report No. TR-1. 136 pp. http://hdl.handle.net/10402/era.17555

Abstract: The search for a viable tailings dewatering technology will intensify as the already large quantities of liquid waste products generated by the oil sands industry grows and tailings storage facilities fill nearer to capacity. BGC Engineering Inc. (BGC) conducted a review of existing tailings technologies for the Oil Sands Research and Information Network (OSRIN).

Over the years, many technologies have been proposed and field tested but they have been rejected for lack of technical or economic feasibility. With no unique and acceptable solution yet in sight, research is now focusing on schemes which utilize more than one technology and combining them into a disposal package.

This report presents an in-depth review of the state-of-knowledge related to oil sands fine tailings treatment technologies. All information is from publicly available sources at the time of writing. The aim of this report is to serve as a fundamental planning document for future research initiatives by OSRIN and other research agencies to support, promote, and improve the oil sands industry's capability to deal with the challenges of fine tailings management.

BGC and OSRIN compiled these references by contacting industry, government, and university researchers, as well as from searches of electronic databases and our own files. We identified 34 oil sands tailings treatment technologies that are discussed and analyzed from a fundamental and practical point of view. The technologies were divided into five groups:
(i) Physical/Mechanical Processes, (ii) Natural Processes, (iii) Chemical/Biological Amendments, (iv) Mixtures/Co-disposal, and (v) Permanent Storage.

Considerable research has been conducted to date to develop improved understanding of tailings behaviour, as well as the performance of various treatment technologies so the body of literature in this area is very large. We have collated a large number of references from which this synthesis was developed, and provided these references in a pdf format for more in-depth review by researchers. Researchers are encouraged to undertake their own detailed review of available references to better understand what has been done and learned to date.

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2.1.16 *Silicon Nanoparticle Membranes for Photocatalytic Oil Sands Process Water Treatment – Dr. Johnathan Veinot, University of Alberta*

Report: Iqbal, M., T.K. Purkait, M. Aghajamali, L. Hadidi, J.G.C. Veinot, G.G. Goss and M. Gamal El-Din, 2014. Hybrid Aerogel SiNP Membranes for Photocatalytic Remediation of Oil Sands Process Water. OSRIN Report No. TR-54. 29 pp. http://hdl.handle.net/10402/era.40004

Abstract: There are many candidate technologies that could be applied to the treatment of oil sands process-affected water (OSPW). Advanced oxidation processes (AOPs) are particularly useful for degrading biologically toxic or non-degradable materials such as aromatics, pesticides, petroleum constituents, and volatile organic compounds in wastewater.

AOPs based on photocatalysis using nanomaterials are promising due to the high surface area, and exquisite tunability of surface chemistry afforded by the nanoparticles as well as the potential for harnessing sunlight as a passive, cost-effective energy source to initiate the reactions. However, application of these attractive materials in large-scale operations remains a challenge. To address these challenges, photocatalytic reactors have been proposed that utilize nanoparticle slurries or nanoparticles immobilized on various membrane supports. Ceramic membranes are often preferred because of their thermal and chemical stability. Recently, another class of support known as aerogels has attracted attention in absorption-based remediation. To date, there is a lack of reports in which these materials or nanomaterial hybrids have been applied as photocatalytic membranes.

In this report, we present new hybrid silica aerogels that contain Si nanoparticles (SiNPs). The aerogels are produced using versatile and straightforward sol-gel reactions in the presence of SiNPs. Monoliths of the final SiNP-containing aerogel are obtained after drying in supercritical CO_2 and have extremely high surface areas (>1,000 m^2/g) as well as uniform and narrow pore structures. These hybrid aerogels offer distinct advantages of low density, high surface while maintaining the characteristics of immobilized SiNPs.

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2.1.17 *Standard Operating Procedures and Physical Properties of Oil Sands Naphthenic Acids – Dr. Haneef Mian, NAIT Applied Research Center for Oil Sands Sustainability*

Report: Mahdavi, H., H. Mian, S. Hepperle and Z. Burkus, 2014. Standard Operating Procedures for Analysis of Naphthenic Acids from Oil Sands Process-Affected Water. OSRIN Report No. TR-62. 67 pp. http://hdl.handle.net/10402/era.40181

Abstract: Naphthenic acids (NAs) are considered the main source of chronic and acute toxicity in oil sands process-affected water (OSPW). The purpose of this investigation is to establish elements of a standard procedure to determine and minimize the amount of NA loss during storage, sample preparation and pretreatment, and radiation emission such as sunlight, microwave and ultraviolet. In addition, efficiency of solid phase extraction (SPE) and industrial resins for NA separation from aqueous phase were studied.

For quantification of NAs, fluorescence spectroscopy was used, which requires minimum sample manipulation. Two different types of NAs, OSPW-associated (O-NAs) in oil sands process-affected water as well as Merichem NAs (M-NAs) dissolved in phosphate buffer (0.05M, pH = 8.5), were tested and compared in this research. The lowest NA loss among the tested filter membranes was observed in the PVDF filter membrane (Durapore 0.45 µm, Millipore), and among the tested filter syringes was observed in the Target GL microfiber (0.7 µm, National Scientific). Pre-wetting PTFE membranes with methanol may increase the NA loss. According to our observations, no significant difference was detected between the PVDF filter membrane (Durapore 0.45 µm, Millipore) and centrifugation in glass tubes (30 min, 3500 ×g) for solid separation (P-value>0.05).

For storage containers, the best performance (smallest NA loss) was observed in lime-soda and borosilicate glass; however, glass silanization may increase the adsorption of M-NAs on the glass surface. Significant M-NA loss was observed in all three plastic bottles (HDPE, LDPE, and PP). Despite that no significant reduction in concentration of O-NAs was observed, long term storage in plastic bottles is not suggested. Three types of centrifuge tubes (polypropylene ultra-high-performance (PP-UHP), polypropylene high-performance (PP-HP), and polystyrene) were tested and high M-NA loss was observed, especially in polystyrene centrifuge tubes. Similar to the plastic bottles, no considerable O-NA loss was detected, but long term storage in centrifuge tubes is not suggested because it is expected that those NA molecules with similar structure to M-NAs are suspected to be adsorbed on the surface of any plastic made containers.

The best storage condition was storage in the fridge (4°C). Addition of methanol (50% v/v), pH increase to 11.1, or pH reduction to 2.1 caused false-positive and false-negative errors in NA concentration measured by fluorescent instrument. Freezing did not influence the NA concentration, however, possible NA loss due to storage in a plastic bottle or centrifuge tube should be taken into consideration. In the cap liner material test, the best performance was seen for PTFE and Tinfoil cap liners. The leakage of contaminants, interfering with NA measurement, from white rubber and polyethylene cap liners was seen. For long term storage of water samples, the PTFE cap liner is suggested.

Small reduction in M-NA concentration was observed after UV exposure, but the microwave did not influence either M-NAs or O-NAs. In rotavapor experiment with O-NAs, it was found that O-NA loss increases at low pH (2); however for M-NAs, no considerable difference in NA loss was seen at high (9) or low pH (2). The highest NA loss was observed in DCM solvent.

The C18 SPE laboratory cartridge and L493 industrial resins displayed the best performance (in terms of NA adsorption from aqueous solution and subsequent NA release into the eluent solution) among the tested SPE cartridges and industrial resins.

The results from this investigation elucidated the unknown aspects of sampling, storage conditions, and processing of NA containing water samples. Still, more investigations are required to optimize the performance of SPE laboratory cartridges and industrial resins. For future research, the amount of recovered NAs from industrial resins can be optimized by using various eluent solutions. The type of eluent solution is crucially important for further treatment of NAs on an industrial scale.

In addition, in this research only one type of OSPW sample was tested. It is hypothesized that if the OSPW sample is fresh or derived from a refinery, there is a chance that such a sample may behave in a similar fashion to M-NAs. Long-term storage and consecutive use of storage containers may also result in serious losses.

Measurement of NA using fluorescence instrument requires a minimum sample preparation and manipulation which reduce the error from NA loss. However, this method comes with some inherent issues in terms of accuracy. For future research we suggest that a high resolution instrument is used for quantification, fingerprinting and characterizing of NA molecules.

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2.1.18 *Tailings Dewatering Technology Review – Kevin Biggar, BGC Engineering*

Report: BGC Engineering Inc., 2010. Review of Reclamation Options for Oil Sands Tailings Substrates. OSRIN Report No. TR-2. 59 pp. http://hdl.handle.net/10402/era.17547

Abstract: BGC Engineering Inc. (BGC) conducted a scoping study of the state of knowledge related to technologies for reclaiming oil sands tailings substrates to upland boreal forests and wetlands for the Oil Sands Research and Information Network (OSRIN). The objective of the scoping study is to help establish an understanding of the status of fine tailings reclamation technology in the Athabasca Oil Sands Region (AOSR). Relevant research was compiled from peer reviewed and non-peer reviewed sources including journals, conference proceedings, magazine articles, internal and consultant reports. Industry researchers and academics were contacted for their information.

Until recently, a wet landscape scenario, in which mature fine tailings (MFT) would be stored in pits and capped with a layer of freshwater to form an artificial lake, was the most likely reclamation option for MFT. In this scenario, pit lakes (PL), or end-pit lakes (EPL) are designed to remediate process-affected waters from tailings landforms through bioremediation and dilution. As an alternative to water-capping, much of the current research has focused on reclamation technologies that would result in a dry landscape.

Reclamation of fine tailings using a dry landscape scenario first requires stabilization of the deposit to allow access for heavy machinery (trafficability). Soil cover designs and revegetation prescriptions are used to reclaim the tailings substrate to an equivalent land capability or ecosystem function. Wetland design and upland forest reclamation are active areas of research in fine tailings reclamation, including the potential impacts of increased salinity on plant species selection, germination and growth.

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2.1.19 *Tailings Water Management Project – Chris Godwalt, Alberta WaterSMART*

Report: Godwalt, C., P. Kotecha and C. Aumann, 2010. Oil Sands Tailings Management Project. OSRIN Report No. TR-7. 64 pp. http://hdl.handle.net/10402/era.22536

Abstract: The Oil Sands Leadership Initiative (OSLI) is a collaboration of five progressive oil sands operators (ConocoPhillips Canada, Nexen Inc., Statoil Canada, Suncor Energy Inc. and Total E&P Canada), with the Government of Alberta participating as an observer, working to advance the development of the oil sands industry in an environmentally, economically and socially responsible manner. The OSLI members identified Water Management as one of the target areas for a step change improvement in performance through collaborative efforts. Alberta WaterSMART was engaged to help develop and manage the various projects arising from the work in water management. One of the projects with the highest potential for achieving results was the development of a regional water management solution.

Currently, oil sands producers in the Athabasca Region optimize water sourcing and disposal individually with a focus on fresh water conservation and economics. Mines source water from the Athabasca River with no discharge of process-affected water to the river, while Steam Assisted Gravity Drainage (SAGD) operators are considering distant saline aquifers for their source water requirements.

The Tailings Water Management Project is Phase 1 of a four phase project to study the Environmental and Economic Footprint (EEF) benefit of collaborative solutions for Athabasca oil sands production water supply and disposal. The specific goal of this Project was to identify tailings treatment technologies which could be implemented today, and to develop and assess options for optimizing regional oil sands production water sourcing and disposal. Alternatives were split between sub-regionally integrated and regionally integrated solutions in which sub-regional systems used a common SAGD supply and mines managed their disposal needs independently, and regionally integrated solutions involving completely integrated mining/SAGD solutions by transferring tailings water to SAGD operations. Sub–regionally integrated SAGD water source alternatives included the Athabasca River, saline aquifers, and municipal wastewater. Regionally integrated alternatives combined mine water disposal and SAGD water supply. Rather than focusing solely on fresh water conservation and economics, alternatives were assessed on the basis of their total EEF, including greenhouse gas emissions, wastes produced, and land disturbance. Alternatives were evaluated using a consequential life-cycle assessment methodology, focusing on quantifying key performance indicators relative to baseline operations.

While the intent of the Tailings Water Management Project was to develop and present solution alternatives and opportunities for regional optimization, the project did not attempt to rank potential solutions. Impact categories quantitatively assessed footprint. However, it was not possible to quantify the effects of all issues (for example the degradation of a saline aquifer or the reduction in tailings TDS) in these numerical calculations. As ranking systems are ultimately the result of an assessment of social choices which are qualitative in nature, there is inherent uncertainty regarding how stakeholders will value different quantitative and qualitative impacts. While methods exist to help stakeholders arrive at such decisions, rankings will still vary depending on group composition and goals. Thus, the results of this project provided the “raw material” to advance subsequent discussions on this topic.

Directionally, Phase 1 results supported the premise that large, regionally integrated solutions have a lower EEF than sub-regional systems. Results further indicated that there are existing tailings treatment technologies which, with more testing and development, may be viable for commercial deployment by 2015. Regional water management solutions out-performed sub-regional options on all indicators, except for Fresh Water Consumption. Sub-regional water management solutions out-performed regional water management solutions for Fresh Water Consumption only by degrading saline aquifers. However, it was questionable whether saline aquifers had the capacity to deliver the volumes of water needed to support future SAGD operations. Based on this analysis, OSLI is proceeding to Phase 2 of the project, developing the most promising alternatives including the business models to implement the selected solutions.

While the OSLI Tailings Water Management Project was able to conclude that regionally integrated solutions have a lower EEF, the work conducted was directional in nature due to the limited time available, data used, and knowledge gaps identified. In addition to selection and development of preferred alternatives, Phase 2 of the Regional Water Management Solutions Project will need to address the following issues:

- Improving data reliability through incorporating actual operational data and company forecasts
- Conducting research to fill the knowledge gaps identified
- Piloting tailings treatment technologies to generate data required for design of full scale facilities

Finally, while operational data, further analysis, research and piloting will allow more accurate calculation of the impacts of the different design alternatives, ranking the design alternatives requires engaging with stakeholders to rank these solutions based on the quantitative and qualitative factors discussed above. This requires guidance from both government and industry regarding which stakeholders to engage in order to validate and select the "best" solution for implementation.

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3 REGIONAL LANDSCAPE RECLAMATION PROGRAM

This program focuses on providing the knowledge necessary to support development of regional reclamation targets as well as site- and mine-level objectives.

Project	Researcher
Completed Projects	
A Framework for Wildlife Habitat Design for Oil Sands Mine Reclamation: Building Wildlife Communities from the Bottom Up	Dr. Brian Eaton, Alberta Innovates – Technology Futures
Assessment of Safety Concerns Related to Tree Planting on Active Tailings Dams	Barry Hurndall, BJH Engineering
A Tool for Adaptation Decision-Making in Oil Sands Reclamation Under Risk of Climate Change	Dr. Clive Welham, University of British Columbia
Boreal Plant Species for Reclamation of Athabasca Oil Sands Disturbances	Ann Smreciu, Wildrose Consulting, Inc.
Conducting a Dialogue 'Challenges and Timelines in Reclamation and the Feasibility of Alternative End Land Uses'	Keith Jones, Innovation Expedition Consulting Inc.
Development of a Geomatics Monitoring Tool for Oil Sands Reclamation Monitoring	Dr. Karl Staenz, University of Lethbridge
Equivalent Land Capability Workshop	Mark Polet, Klohn Crippen Berger

Project	**Researcher**
Evaluating Use of Biochar for Oil Sands Reclamation	Dr. Derek MacKenzie, University of Alberta
Factors Affecting Ecological Resilience of Reclaimed Oil Sands Uplands	Dr. Clive Welham, FORRx Consulting Inc.
Future of Shrubs in Oil Sands Reclamation Workshop	Oil Sands Research and Information Network, University of Alberta
Oil Sands Terrestrial Habitat and Risk Modeling for Disturbance and Reclamation (Phase I)	Dr. Clive Welham, FORRx Consulting Inc.
Oil Sands Terrestrial Habitat and Risk Modeling for Disturbance and Reclamation (Phase II)	Dr. Clive Welham, FORRx Consulting Inc.
Oil Sands Terrestrial Habitat and Risk Modeling for Disturbance and Reclamation (Phase III)	Dr. Clive Welham, University of British Columbia
Oil Sands Wetlands Assessment Training Video	Brenda Rooney, Rooney Productions
Potential Impacts of Beavers on Oil Sands Reclamation Success	Dr. Brian Eaton, Alberta Innovates – Technology Futures
Preliminary Watershed Hydrology and Chemical Export Model for Reclaimed Oil Sands Sites	Dr. Gordon Putz, University of Saskatchewan
Reclamation Alternatives Dialogue Assessment and Design	Keith Jones, Innovation Expedition Consulting Inc.
Resiliency of Reclaimed Boreal Forest Landscapes	Matthew Pyper, University of Alberta
Review of Alternative Seed Packaging and Delivery Systems for Oil Sands Reclamation	Dr. Amanda Schoonmaker, Northern Alberta Institute of Technology
Role of Professional Expertise in Reclamation Certification	Roger Creasey, Terrain FX Inc.
Soil Microbiology as an Index of Oil Sands Reclamation Success	Dr. Sylvie Mercier Quideau, University of Alberta
Soil Nitrogen Indicators for Land Reclamation	Dr. Scott Chang, University of Alberta
Support Wetland Reclamation Conference	Dr. Dale Vitt, PeatNet
What Constitutes Success for LFH Salvage and Replacement	Dr. Anne Naeth, University of Alberta
Woody Debris Field Guide	Dr. Vic Lieffers, University of Alberta

3.1 Completed Projects

3.1.1 *A Framework for Wildlife Habitat Design for Oil Sands Mine Reclamation: Building Wildlife Communities from the Bottom Up – Dr. Brian Eaton, Alberta Innovates – Technology Futures*

Report: Eaton, B.R., J.T. Fisher, G.T. McKenna, and J. Pollard. 2014. An Ecological Framework for Wildlife Habitat Design for Oil Sands Mine Reclamation. OSRIN Report No. TR-67. 83 pp. http://hdl.handle.net/10402/era.40338

Abstract: Oil sands companies are required to reclaim the land that has been disturbed during their operations to self-sustaining, locally common boreal forest. An important facet of the reclaimed landscape is support of locally-relevant wildlife communities. Wildlife communities are an important part of the biodiversity of the post-mining landscape, and are crucial elements of the traditional landscape for First Nations and other users of the land.

The current philosophy of "Build it and they will come" (the *Field of Dreams* hypothesis) should be replaced by applying wildlife and landscape ecology principles to mine reclamation, to effectively achieve wildlife habitat and other end land-use goals. A new ecological framework for wildlife reclamation that fits with operational practices is needed. Here we provide this framework, and outline some of the first steps toward a research and demonstration program that will improve success in wildlife reclamation in the mineable oil sands region.

Because natural systems are so complex, we do not have the ability to fully understand the intricacies of wildlife habitat and communities, or their interactions with each other and their environment. However, we can adopt natural analogs, using reference conditions and the range of natural variation, to guide our reclamation designs. For example, diversity in boreal forest habitat is largely driven by wildfire cycles. We can emulate the effects of natural disturbances such as wildfire by designing a mosaic of interconnected patches with a diversity of sizes and shapes on the reclaimed landscape, adding in artificial snags as surrogates for structures that would naturally remain after fire, etc. By emulating natural systems, we are more likely to impart ecological form and function to the systems we design and build.

Such wildlife design for oil sands mine reclamation needs to be done with explicit consideration of spatial and temporal scales:

- Spatial – includes region, lease/landscape, landform, patch, and microsite. These scales are readily incorporated into normal mine planning frameworks which roughly align with these scales.
- Temporal – project phases include planning, design and implementation; forest stand development stages include initiation, establishment, organization, maturity, and old growth. Considerations of temporal scale provide the opportunity for adjustments to vegetation and wildlife enhancements on the reclaimed landscape over time.

Designing for connectivity is a key spatial feature of the new framework. The need has been long recognized but little guidance is available. Some methods are recommended here for addressing this need. Connectivity may be designed using a number of methods, including habitat corridors and stepping stones.

The temporal aspects of reclamation are as important, though less developed here. It is recognized that revegetation of a site is not a one-time activity, but that there are opportunities to stage the revegetation for better emulation of natural systems, allowing better creation of midstory and understory over the first decades of mine reclamation. This mimics natural processes in which vegetation communities change over time since disturbance, with accompanying changes in faunal communities as sites age.

We recommend formal active adaptive management, where sites will be monitored and vegetation and wildlife habitat elements will be adjusted over time based on performance data. As part of this approach, clear goals must be set at the closure planning levels; these goals must be measurable and defensible. Wildlife habitat creation goals in particular are needed.

In moving to a new paradigm for reclaiming for wildlife habitat, we need to avoid the lure of designing for specific species and instead focus at the community level. Much of this can be accomplished through use of planting to ecosite in a more thoughtful and interconnected way.

We provide a useful method for communicating reclamation guidance: design and element sheets. Each sheet is focused on a particular aspect of wildlife reclamation, such as habitat patch size and shape or how to prepare, distribute and install artificial snags. Approximately 40 to 60 sheets are proposed and drafts of the first two are supplied here. These sheets are aimed at designers (design sheets) and field practitioners (element sheets), and contain guidance supported by ecological data and extensive references.

The first iteration of the wildlife habitat reclamation framework is offered here, but we acknowledge that there is considerable work needed to refine it, update it with new research, and populate the design sheets over time. Research and demonstration projects would address some of the most pressing data gaps and assist in technology transfer to oil sands operators and reclamation practitioners.

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3.1.2 *Assessment of Safety Concerns Related to Tree Planting on Active Tailings Dams – Barry Hurndall, BJH Engineering*

Report: Hurndall, B.J., N.R. Morgenstern, A. Kupper and J. Sobkowicz, 2011. Report and Recommendations of the Task Force on Tree and Shrub Planting on Active Oil Sands Tailings Dams. OSRIN Report No. TR-11. 15 pp. http://hdl.handle.net/10402/era.22782

Abstract: Dam safety concern over the planting of trees and woody shrubs is in conflict with progressive reclamation, which is also a desirable outcome for oil sands tailings dams. International dam safety practice commonly restricts trees and woody shrubs on the downstream slopes of dams to preclude damage to drains, aggravation of seepage and piping and to ensure the integrity of both visual and instrumentation monitoring which require access and clear sight lines.

To address this issue, Alberta Environment (AENV) requested the Oil Sands Research and Information Network (OSRIN) to convene a third-party Task Force to provide independent opinion and recommendations on the subject.

The Task Force met in December 2010 and has recommended that provision for trees and woody shrubs on the slopes of active oil sands tailings dam shall be considered part of the responsibility of the Engineer-of-Record and plans will be submitted to AENV, Dam Safety for approval. The Task Force appreciates that it will be customary for the Engineer-of-Record to consult with corporate reclamation specialists for input into the recommended tree and shrub planting zones and tree and shrub exclusion zones. Potential exclusion zones include local critical areas such as drains, liners, berms, drain outfalls, ditches, access ramps and adjacent to instrumentation, etc.

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3.1.3 *A Tool for Adaptation Decision-Making in Oil Sands Reclamation Under Risk of Climate Change – Dr. Clive Welham, University of British Columbia*

This project was jointly funded with the Cumulative Environmental Management Association (CEMA) and Natural Resources Canada (NRCan).

Report: Welham, C., 2014. Risk and Uncertainty in Oil Sands Upland Reclamation: Best Management Practices within the Context of Climate Change. OSRIN Report No. TR-61. 26 pp. http://hdl.handle.net/10402/era.40171

Abstract: The focus of most climate change impact studies to date is on changes related to mean climate conditions. In terms of climate model output, these changes are more robust than changes in climate variability, the latter of which has considerably greater uncertainty. By concentrating on climate means, however, the full impacts of climate change are probably being seriously underestimated. This report discusses and illustrates how the risk and uncertainty introduced by climate change can be incorporated into reclamation planning.

Two approaches to reclamation planning are described. In the first approach, best management practices are developed using a deterministic methodology. A deterministic system is assumed to always produce the same output from a given starting condition or initial state. A corollary to this approach is that practices are geared to achieving the long-term average outcome. As long as this average satisfies management goals, variation is considered to be minimal and/or of little significance. The vegetation prescriptions provided in the Revegetation Manual are an example of a deterministic methodology. A fundamental assumption underpinning the validity of the approach is that past performance constitutes a reliable index of future performance. In the case of oil sands reclamation, this assumption is questionable for two reasons. First, oil sands reclamation soil materials possess biogeochemical properties and conditions that differ fundamentally from natural systems. Second, climate change is a source of uncertainty. It is anticipated to be a major chronic disturbance because of the northerly location of the oil sands.

In the second approach, reclamation planning is undertaken using a stochastic methodology. This approach assumes that system development occurs along a trajectory dictated by one or

more random variables (decision points). Each decision point thus represents an opportunity for the system trajectory to be altered by changes in the value of its random variables. Climate and climate change are likely the most important random variables influencing the developmental trajectory of reclaimed ecosystems. In this respect, the impact of climate as a driver of ecosystem performance needs to be considered. Under a stochastic, risk-based approach, the two basic principles of reclamation planning are:

1. That it represents the balance between the probability of an undesirable outcome and the marginal improvement in outcome from an additional unit of investment (increased capping depths or higher planting densities, for example), and
2. The greater uncertainty in outcome, the more conservative should be the management inputs (i.e., the higher the level of effort).

One consideration in accounting for climate change is timescale. Over the next several decades, uncertainty in climate predictions will be predominantly a consequence of natural climatic variability. The relative effect of climate change increases significantly thereafter, which means the climate signature will become clearer and more predominant during the latter decades of this century. The implications for reclamation planning are that prescriptions suitable for establishing stands under current climate conditions may prove inadequate in the future, and short-term trends in vegetation performance may not be a reliable index of future performance. Changes in the disturbance regime associated with wildfire and insect epidemics are not given explicit consideration in reclamation planning. These risks add considerable uncertainty to assumption that current practices will be suitable for achieving long-term objectives.

From a reclamation perspective, stand-level outcomes are a necessary prerequisite to successful reclamation, particularly if performance is focused on utilitarian metrics (merchantable volume, for example). Evidence suggests, however, that for the public at large, reclaimed areas are more likely to be evaluated in terms of their amenities, such as scenic beauty, ‘naturalness’, and recreational value – landscape-level attributes. The boreal mixedwood landscape has been characterized as a ‘mosaic’ of stands of differing age and species composition. At least part of this spatial heterogeneity will be created on mine sites because reclamation occurs progressively, which will ensure heterogeneity among stand ages. A second option for creating heterogeneity is to ‘plan for failure’ (PFF). Under a PFF strategy, stands are expected to vary in their developmental trajectories, with some stands transitioning to a different end land-use than originally intended. This variation constitutes the basis on which the desired level of heterogeneity is achieved. Another option is to actively manage for landscape heterogeneity by varying capping and planting prescriptions on a stand-by-stand basis. The advantages and disadvantages of these options are discussed. Changes in the disturbance regime (wildfire or insect epidemics) could largely render moot concerns around uncertainties in development trajectories.

A fundamental challenge to assessing current best management practices within the context of climate change is the questionable utility of relying on historical practices for guidance. The success of a particular reclamation prescription in meeting long-term objectives can, in principle, be assessed empirically. In practice, however, many years must elapse before a reclaimed stand has developed sufficiently that a given prescription can be evaluated definitively or that interim measures are a reliable proxy for long-term outcomes. Modeling of ecosystem development is perhaps the only practical approach to resolving to this dilemma.

There have been two basic approaches to predictive modelling of ecosystem response to a changing environment: empirical (statistical)- and process-based models. Here, a stochastic approach is described in which probability outcomes are derived for reclamation planning using the FORECAST Climate model and a state-and-transition model (STSM). FORECAST Climate is used to project vegetation development (i.e., 'states') for a given reclamation land unit (e.g., dry, moist rich, moist poor, wet rich, and wet poor) subject to current and alternative management options, disturbance regimes, and two climate change scenarios. The probabilities associated with each state transition are then be derived from these runs. The STSM simulates vegetation development for reclamation land units over time and across an entire mine footprint. By implementing a Monte Carlo experiment (i.e., repeated iterations through the STSM) in conjunction with the transition probabilities from FORECAST Climate, uncertainties in outcome for a given reclamation practice are assessed as a consequence of climate change.

Model output will permit stakeholders and regulators to evaluate the efficacy of current and alternative adaptation strategies with respect to mitigating risk of undesirable outcomes due to climate change. In addition, the STSM will be provided with the capability for geospatial representation of each land unit and land unit phase. This functionality will aid mine operators in meeting approval conditions regarding integration across lease boundaries and with undisturbed areas. The tool will also be useful for wildlife habitat planning and assessment of reclamation performance with respect to re-establishing wildlife habitat (both of which have a strong spatial component).

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3.1.4 *Boreal Plant Species for Reclamation of Athabasca Oil Sands Disturbances – Ann Smreciu, Wildrose Consulting, Inc.*

Report: Smreciu, A., K. Gould and S. Wood, 2013. Boreal Plant Species for Reclamation of Athabasca Oil Sands Disturbances – Updated December 2014. OSRIN Report No. TR-44. 23 pp. plus appendices. http://hdl.handle.net/10402/era.37533

Abstract: Oil sands reclamation guidance documents prepared by the Cumulative Environmental Management Association and endorsed by the provincial government include lists of potential reclamation species and their characteristics (Alberta Environment 2008, 2010). This report consolidates and updates profiles for 98 of these species.

Each profile contains the following information (where applicable):

- Species Nomenclature – up-to-date scientific names and widely used common names along with plant family designations; common names should be used with caution as many distinct species have the same or similar common names and common names may vary by region

- Plant Description
    - Fruit
    - Seed
- Habitat and Distribution of the species locally and worldwide
    - Seral Stage
    - Soil
    - Distribution based on Moss (1983) unless otherwise noted. Moss uses the following convention to describe distribution:
      The North American distribution is generally given in two tiers from west to east across the continent. The first tier represents the northern limit, the second tier the southern limit. A comma indicates a reasonably continuous distribution and a semi-colon indicates a disjunction.
- Phenology – particularly based on observations from north eastern Alberta
- Pollination mechanisms are described if known.
- Genetic Information (ploidy)
- Known Symbioses
- Seed Processing
    - Collection
    - Seed Weight
    - Harvest Dates
    - Cleaning
    - Storage Behaviour
    - Storage
    - Longevity
- Propagation – including seed and vegetative propagation
    - Natural Regeneration
    - Germination
    - Pre-treatments
    - Vegetative Propagation
- Greenhouse timelines for seedling production

- Aboriginal/Food Uses
  - Food
  - Medicinal
  - Other
- Wildlife/Forage Usage
- Reclamation Potential – with examples from oil sands reclamation studies where available
- Commercial Resources
  - Harvest Methods
  - Availability
  - Cultivars
  - Uses (other than the Aboriginal uses noted above)
- Notes – including comments on alternative names (genera and species names change with increasing knowledge of biology and genetics; caution should be used when consulting older references such as Budd and Best (1969) and Moss (1983) because of potential name changes since these were published)

Each profile is illustrated with photographs of the plant, flowers, fruit and/or seeds if available and line drawings are also included if available (Budd and Best (1969) is an excellent source for line drawings). References for the content are provided with each profile.

Although the original objective for the profiles was to inform decisions made by reclamation planners and practitioners in the oil sands and to promote the inclusion of these species in revegetation, the information has a much wider audience appeal. We continue to be inundated with requests for all types of species information from professionals in other industries as well as provincial, municipal and federal government agencies, nursery producers, aboriginal groups, researchers, archeologists, cultural anthropologists and ethno-botanists, wildlife biologists, foresters, range managers, horticulturalists, naturalists and the general public. At the November 25, 2013 OSRIN workshop *Future of Shrubs in Oil Sands Reclamation* participants noted a lack of awareness of, and in for many species the need for, the types of information contained in these species profiles.

This report is a valuable tool for those directly responsible for planning and executing reclamation in the oil sands as well as for other professionals involved in native plant work.

All of the species profiles have been posted to OSRIN's website at http://www.osrin.ualberta.ca/Resources/RevegSpeciesProfiles.aspx

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3.1.5 *Conducting a Dialogue 'Challenges and Timelines in Reclamation and the Feasibility of Alternative End Land Uses' – Keith Jones, Innovation Expedition Consulting Inc.*

Report: Jones, R.K. and D. Forrest, 2010. Oil Sands Mining Reclamation Challenge Dialogue – Report and Appendices. OSRIN Report No. TR-4. 258 pp. http://hdl.handle.net/10402/era.19092

Also available as a shorter version without the detailed appendices – Jones, R.K. and D. Forrest, 2010. Oil Sands Mining Reclamation Challenge Dialogue – Report. OSRIN Report No. TR-4A. 18 pp. http://hdl.handle.net/10402/era.19091

Abstract: This report provides a high level summary of the conversations and discoveries that emerged over the course of the Reclamation Challenge Dialogue. During the first two months of 2010, OSRIN explored the idea of the dialogue with a number of key stakeholders who were either directly involved in or affected by the oil sands reclamation challenge. These discussions confirmed its value in having such a dialogue and provided guidance on what particular challenges were most important to focus on.

Over 100 participants across the oil sands reclamation community of interest and practice were invited to respond to the Challenge Paper. Feedback was received from 43 individuals, including responses from governments, individuals working with First Nations in the oil sands area, academia, consulting firms, oil sands companies, research/technology agencies and nongovernment organizations. Many responded in considerable detail; over 100 pages of feedback were compiled unattributed into a Consolidated Feedback Document. This material was then synthesized into a Progress Report supplemented by a detailed Progress Report Appendix. Both the original feedback and the Progress Report material contain a wealth of information that can and should be capitalized on further.

While the Challenge Paper intended to focus on a few key aspects of the reclamation challenge for mining in the oil sands area, it ended up provoking a wide range of reactions across almost the full spectrum of the "oil sands reclamation system." The nature and depth of the responses underscored the complexity, diversity and interconnectivity of the numerous reclamation issues and opportunities presented. The responses also indicated how much people wanted to express their views on these challenges. It was obvious that the respondents put considerable effort into articulating thoughtful feedback. These were not just subjects of professional interest but were matters that evoked strong, passionate feelings. Clearly there are some strongly held but also widely divergent beliefs on certain topics.

All of this feedback and its synthesis informed the design of the June 17th Workshop, which was held at the University of Alberta in Edmonton and attended by 38 people. The workshop was supported by a Workshop Workbook. The results of the workshop were summarized in a Workshop Synopsis document that was distributed in early September.

Based on the feedback to the Challenge Paper the Workshop scope was narrowed to create a systems view of oil sands reclamation with a particular focus on key components: (1) challenges related to the rationale and application of the equivalent land capability concept; (2) challenges

related to end land use selection; and (3) challenges related to how to respond to and inform the public's expectation of reclamation success.

Two different approaches to developing a reclamation system "map" were tested with Workshop participants.

Eleven recommendations were developed from the ideas generated by the Challenge Dialogue process.

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3.1.6 *Development of a Geomatics Monitoring Tool for Oil Sands Reclamation Monitoring – Dr. Karl Staenz, University of Lethbridge*

Report: Rochdi, N., J. Zhang, K. Staenz, X. Yang, D. Rolfson, J. Banting, C. King and R. Doherty, 2014. Monitoring Procedures for Wellsite, In-Situ Oil Sands and Coal Mine Reclamation in Alberta – December 2014 Update. OSRIN Report No. TR-47. 167 pp. http://hdl.handle.net/10402/era.38742

Abstract: The scope of the *Monitoring Procedure for Reclamation in Alberta (MOPRA)* project is to develop a geomatics-based monitoring system to support the Government of Alberta's efforts for monitoring reclamation success. This software will support the decision making process to screen almost all oil and gas wellsites and prioritize those that require immediate intervention allowing an efficient allocation of government resources.

Using remote sensing technologies, the following three types of information were pursued:

- Baseline maps of the pre-disturbance condition of sites,
- Vegetation condition related to species, and canopy structure, and vegetation productivity, and
- Temporal change of land condition in reclaimed areas.

The project provided the opportunity to assess remote sensing technologies including optical multispectral, hyperspectral and LiDAR, for monitoring vegetation condition in reclaimed wellsites and mine areas. Three study areas were assessed, sampling both wellsites and a coal mine areas, which cover different landscapes including forested, and agricultural areas.

A set of land products were developed within this project, including baseline land cover, land-cover change, canopy height, fractional cover, tree species and canopy leaf area index (LAI). In addition, multi-year profiles of vegetation index data were examined to assess vegetation regrowth in wellsites in comparison to undisturbed reference areas. Canopy structure attributes, derived from LiDAR data such as canopy height and fractional cover, were also examined to assess differences in vegetation structure between reclaimed wellsites and regenerated burnt/clear-cut areas. In addition, a reclamation monitoring system, composed of a *Remote Sensing Data Processing Toolbox* and *A Stand- Alone Assessment Tool*, was developed.

The land products derived from remote sensing data provide information related to some of the landscape and vegetation assessment parameters adopted within the 2010 reclamation criteria document (Alberta Environment and Sustainable Resource Development 2013), such as bare areas, vegetation species, land-use change, canopy height, percent canopy cover and vegetation quantity/quality.

The achievements of the MOPRA project have highlighted the benefits that remote sensing technologies can provide in support of reclamation monitoring efforts. Having access to a synoptic view of reclaimed lands at the landscape and regional level is of value for assessing land-use cumulative effects and making decisions in line with an integrated resource management system.

While the MOPRA outcomes have shown promise in this direction, there is still a need to test and validate the information extraction approaches adopted as well as the monitoring system developed on various landscapes, such as wetlands, rangelands, agriculture and forested areas. Although, this project has focused on reclaimed wellsites and reclaimed areas within coal mines, the work undertaken can be applicable to natural areas as well as reclaimed lands that have been disturbed by other activities, such as transportation corridors, wind energy, sand and gravel operations, oil sands mines as well as pipelines.

To move towards an integration of remote sensing technologies as an operational monitoring tool, the MOPRA monitoring system would require further testing, involving consultants, industry (e.g., oil and gas, coal mine, wind energy farms), and monitoring organizations (Alberta Environmental Monitoring, Evaluation and Reporting Agency – AEMERA) and regulatory agencies (e.g., Alberta Energy Regulator, ESRD).

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3.1.7 *Equivalent Land Capability Workshop – Mark Polet, Klohn Crippen Berger*

Report: Oil Sands Research and Information Network, 2011. Equivalent Land Capability Workshop Summary Notes. OSRIN Report TR-13. 83 pp. http://hdl.handle.net/10402/era.23385

Abstract: The Equivalent Land Capability Workshop, held on November 26, 2010 at the University of Alberta, provided an opportunity for 60 reclamation specialists to share views about Equivalent Land Capability and how it is applied to oil sands mine reclamation, and to identify research and information needs.

The purpose of the workshop was to develop a shared understanding of the concept and application of Equivalent Land Capability (ELC) as it applies to oil sands mine reclamation.

The workshop format was a series of presentations, each followed by group discussions, which were guided by a series of questions provided by the organizers. A final open forum plenary discussion asked what people had learned and what they felt the next steps should be.

There was general agreement that government should develop a policy document on what ELC means today, and acknowledge that the vision may change in the future. The policy document should acknowledge that ELC is much broader than the regulatory definition. ELC is a province-wide issue not just oil sands – therefore the oil sands could be a chapter in a bigger policy document. The policy should clearly distinguish the concept from the practice (implementation, measurement, etc.).

External discussion papers could be also commissioned, with representation from all the publics. The compilation of these papers can act as a pre-policy paper – a synthesis of opinions meant to inform policy. Contributors may need to be paid a stipend. It is not necessary to agree and there can be a diversity of opinions.

Additional recommendations that came out of the meeting are summarized below:

- Revisit 1998 End Land Use Committee Report.
- Re-institute the Development and Reclamation Review Committee as a tool to get better integration of government agency approaches and issues.
- Develop a vehicle for sharing information on ELC (e.g., an ELC Blog).
- Get more reclamation certificate applications in to test the system.
- Poll the public about reclamation expectations and land use options.

Additional ideas were submitted after the meeting:

- Develop a flow chart that shows and explains the different reclamation stages: Define end use goals; Establish baseline inventories and long term monitoring plots; Reclamation planning; Reclamation implementation; Reclamation monitoring; and, Certification assessment.
- Provide an example of an ELC through the various stages to show its change as it is proposed by a proponent after stakeholder involvement, negotiated, and then approved by government.
- Define what other measurement tools there are – indicating where they are appropriate would help.

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3.1.8 *Evaluating Use of Biochar for Oil Sands Reclamation – Dr. Derek MacKenzie, University of Alberta*

Report: Mackenzie, M.D., S. Hofstetter, I. Hatam and B. Lanoil, 2014. Carbon and Nitrogen Mineralization and Microbial Succession in Oil Sands Reclamation Soils Amended with Pyrogenic Carbon. OSRIN Report No. TR-71. 29 pp. http://hdl.handle.net/10402/era.40354

Abstract: Land reclamation of oil sands disturbed boreal forests in Alberta is a challenging task facing companies with surface mine leases. The government requires reclamation to equivalent land capability, which is a vague statement at best. Agronomic theories and methodologies have been applied in the past with mixed success. We believe that ecological theory and new methods, designed to tease apart ecosystem function, should be applied to reclaiming ecosystems similar to native forests. This new reclamation ecology should start with disturbance theory and in boreal Alberta that means recovery from wildfire. All organisms in boreal forests, from the biggest trees to the smallest bacterium, are adapted to regular pulses of fire. Fire causes plant mortality and therefore changes in competition and resource availability. It also results in the

partial combustion of organic matter, which creates pyrogenic carbon (PyC) and changes the soil chemical environment.

Pyrogenic C is the substrate legacy of fire. It is resistant to decomposition and remains in the soil for hundreds of years. It has high surface area and adsorbs organic and inorganic compounds readily, which affects the availability of nutrients. It can be manufactured by an industrial process called pyrolysis, where is referred to as biochar. We believe that rebuilding native forest soils in the reclamation environment will require the use of biochar to stimulate functional similarity to native ecosystems, in terms of nutrient availability and microbial community succession. This is because peat is being used as a reclamation surface soil, but does not follow the typical first-order decomposition kinetics of native forest soils, due to distinct differences in organic matter quality. We believe that PyC will help to align peat decomposition kinetics and retain nutrients in surface soils. We also believe that it will create microbial community diversity and structure to be similar to the NFS.

A 90 day laboratory incubation was conducted to examine the effect of PyC additions on carbon (C) and nitrogen (N) mineralization in two common oil sands reclamation surface soils, peat mineral mix (PMM) and forest floor mineral mix (FFM), and one native forest soil (NFS) recovering from wildfire. Three different kinds of PyC were used in the incubation, including charcoal collected from a local wildfire event, biochar pyrolyzed from willow chips, and petroleum coke, a by-product of oil sands upgrading. Micro-lysimeter chambers were used to build small soil columns of each soil type, to which PyC was added in replicate. These micro-lysimeters allowed for gas sampling from a soil head space for analysis of microbial respiration and therefore activity, and soil solution sampling for analysis of inorganic N. Samples were collected and analyzed on days 0, 1, 3, 7, 10, 14 and then every week after that for the duration of the incubation. After incubation, soil samples were extracted for microbial sequencing by paired end Illumina sequencing of the 16S rRNA gene for bacteria and ITS 1-2 gene for fungi to examine microbial community diversity and structure.

Results indicated that the different PyC types increased C mineralization compared to the control, which suggests that it stimulates microbial activity and therefore respiration similar to the NFS. Literature also suggests that it undergoes some surface modifications at the molecular level upon addition to soils, which we also feel is reflected in the increased respiration. In contrast, PyC caused a decrease in N mineralization, which we believe is the result of N retention on PyC. This stems mostly from the fact that it is counter-intuitive that microbial activity would be increased (respiration), but the product of that activity (inorganic N) decreased. In reality, it is incredibly difficult to measure nutrient retention on PyC, but some literature provides evidence for this theory. PyC did not align decomposition kinetics for PMM as we believed it would, except in the case of N mineralization with biochar perhaps making it a soil amendment worth more attention. Pet-coke consistently performed the same or worse than the control in terms of C and N mineralization.

Molecular sequencing of bacterial DNA showed that PyC, except for pet-coke, increased diversity in both the FFM and NFS, but not PMM which was higher to begin with. In ordination space, there is clear microbial succession from the control to the biochar, which indicates that biochar has a strong effect on the community structure. Fungal sequencing indicated that FFM had the highest diversity which was lowered by biochar to the level of NFS. However, no clear effect of PyC could be established for fungal community structure.

These results clearly indicate that the addition of PyC has an effect on C and N mineralization, and microbial community diversity and structure in oil sands reclamation surface soils. The direction and magnitude of the effects has some similarity to the effect of PyC in NFS, and therefore should be considered as a soil amendment. However, the full interpretation of these results requires more work in terms of prescribing surface soil mixtures that will lead to a high degree of similarity between reclaimed ecosystems and native ecosystems. This work provides some preliminary evidence to support a paradigm shift towards reclamation ecology.

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3.1.9 *Factors Affecting Ecological Resilience of Reclaimed Oil Sands Uplands – Dr. Clive Welham, FORRx Consulting Inc.*

Report: Welham, C., 2013. Factors Affecting Ecological Resilience of Reclaimed Oil Sands Uplands. OSRIN Report No. TR-34. 44 pp. http://hdl.handle.net/10402/era.31714

Abstract: This literature review provides an understanding of ecological resilience as a concept to promote successful land reclamation in Alberta's mineable oil sands region by exploring four key issues:

Defining ecological resilience for boreal forest ecosystems, and assessing whether this definition can be applied to reclaimed oil sands landscapes or requires modification.

Resilience is an emergent property of ecosystems. It is an outcome of their inherent capacity for self-organization – the interaction between structure and process that leads to system development. Resilience constitutes the relative susceptibility of a given community to switches into alternative states as a result of the interaction between autogenic (competition, for example), allogenic (fire, wind, harvesting, and climate, as examples) and biogenic (insect epidemics, diseases, as examples) processes.

In principle, the concept of resilience could have considerable utility in designing reclamation systems for the oil sands. One application of the concept, the length of time that a system takes to return to equilibrium following perturbation (engineering resilience), is to use rates and patterns of development from the natural forested ecosystems in the region as a benchmark. Hence, the resilience of reclaimed systems would be evaluated with respect to the extent to which these patterns and rates are congruent. Several metrics in the current version of the *Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region* (indicator species and similarity indices, for example) suggest the utility of this approach has been recognized, though not necessarily within the context of resilience. Ecological resilience, the amount of perturbation a system can withstand before it moves into a different state, is pertinent

because it constitutes the conceptual basis for designing practices that confer resilience in reclaimed ecosystems. Examples of these practices include minimizing chronic stress (acid deposition, for example), ensuring the rooting zone is conducive to plant establishment and productivity, and a functionally diverse community (both and above and belowground).

Resilience in natural and reclaimed ecosystems are mirror images. Applying the concept in natural systems is to pose the question, "how much can self-organizing capabilities be *perturbed* and still achieve desired outcomes"? In the case of reclamation the question becomes, "how much of the self-organization capabilities of a system must be *created* to achieve desired outcomes?"

Describing a range of ecological and anthropogenic disturbances a reclaimed oil sands upland site might experience

In terms of the ecological disturbances a reclaimed oil sands upland site might experience, these are fire, insects and pathogens, drought, wind, site dominance (invasion) by non-local species (native and non-native), and climate variability. Anthropogenic disturbances include erosion, issues associated with soil structure and related physical properties, salinity and sodicity, contaminants (bitumen, naphthenic acids), excessively high and low soil pH, and climate change.

Describing physical, chemical and biological characteristics of reclaimed upland sites that would confer resilience to the range of ecological and anthropogenic disturbances identified above

Three approaches are described for addressing the physical, chemical and biological characteristics (structure, composition, function) of reclaimed upland sites that would confer resilience to the range of ecological and anthropogenic disturbances identified above. From the general to the specific, these approaches focus on (a) general ecosystem attributes, (b) on functions that need to be maintained, and (c) attributes that confer resilience against specific perturbations or stressors.

Describing reclamation and management practices necessary to generate ecological resilience in oil sands upland landscapes

Managing for resilience is to implement reclamation practices and procedures that maximize the probability a given desired state will emerge or persist over the time period of interest. The underpinning of resilient ecosystems is a rooting zone conducive to plant establishment and productivity, with a functionally diverse community (both above and belowground) to maximize the potential that development will be maintained along desired trajectories. To create resilient ecosystems, management must focus on both mitigative and adaptive strategies. Mitigative actions confer resilience by eliminating or reducing exposure to chronic stresses (nitrogen and sulfur deposition or salt intrusion, for example). The adaptive approach focuses on traits that allow plant species to tolerate chronic stress or that predispose them to changes in the disturbance regime (fire or climate change, for example).

To measure resilience one needs to define the time scale over which a system is resilient, with the choice of scale dependent of the issue under investigation. In the case of reclamation, relevant scales could vary from several decades (the time period over which a reclamation certificate might be awarded) to a century, or more. In principle, resilience could be predicted from models that incorporate the critical processes driving ecosystem productivity and community development but in practice, this is likely not practical due to data limitations. Nevertheless, models can play a useful role in identifying indicators that may signal ecosystem resilience and vulnerability.

The review identifies the top three characteristics that confer ecological resilience in oil sand upland landscapes. These are

1. Species diversity, with a particular emphasis on functional diversity
2. A quality rooting zone
3. Minimize nitrogen and sulfur deposition.

Designing and assessing resilience in reclaimed oil sands ecosystems will likely require a combination of empirical measures informed by model outputs. Models can be used to project the long-term consequences of a given reclamation prescription while specifying which particular ecosystem attributes are relevant to a monitoring program and the time frame when the requirements for a reclamation certificate could be met. In that respect, model outputs, ecological measures, and checklists which identify management activities, decisions and interventions should be developed collectively, and comprise a decision support system that can address the question ‘Does this reclaimed upland site possess or is capable of developing, characteristics of a resilient ecosystem?’

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3.1.10 *Future of Shrubs in Oil Sands Reclamation Workshop – Oil Sands Research and Information Network*

Report: Oil Sands Research and Information Network, 2013. Future of Shrubs in Oil Sands Reclamation Workshop. OSRIN Report No. TR-43. 71 pp. http://hdl.handle.net/10402/era.37440

Abstract: A group of 48 people from government, academia, consultants and the oil sands and plant production industries gathered on November 25, 2013 to discuss the current state of knowledge about shrubs and their current and future use in oil sands reclamation. The Workshop was organized around four key topics:

- Session 1: Regulatory Requirements and Policies
- Session 2: Current State of Knowledge
- Session 3: Knowledge Gaps and Policy Needs
- Session 4: Next Steps

In Session 1, participants noted a number of regulatory requirements and policies that support shrub use. However, a far larger list of impediments was identified. These can be roughly

divided into two main themes: (1) impediments to efficient and effective use of shrubs; and (2) impediments to effective ecological use of shrubs.

In Session 2, participants said we know *which* species to use but maybe not *why* – current planting density rules require x stems/ha and species doesn't matter so there is no incentive for diversity or selection of species attributes that could be exploited to enhance reclamation success. Participants felt collection, storage, growing and seeding issues are understood for 50% to 75% of species but some are very difficult to germinate and grow. They noted that shrubs are not produced commercially in the volumes needed, and this will be even more of a problem when reclamation ramps up in terms of area per year. Participants felt that we have a relatively good understanding of shrub reclamation for *regular reclamation sites* (no inhibiting factors) for both early and late successional species but we are not as advanced for early successional stages in challenging sites and have little knowledge and experience with late successional species in challenging materials. Finally there was the sense that there are lots of people and sources of information available. Much of the information is in grey literature; the comment was made that we also need to recognize *grey knowledge* – the knowledge (generally operational experience of growers and company reclamation staff) that isn't even written down. A better mechanism is needed to access and share the information.

In Session 3, participants provided a long list of characteristics that could be used to determine successful shrub reclamation, but noted that success was seen to be determined by the goal, policy, scale, or timeframe. A long list of research needs was identified, mostly grouped into categories such as: (1) synthesis of existing knowledge, (2) developing *how to* guidance, (3) developing and improving seed management practices, and (4) monitoring outplanting results. In terms of scale of research needed, lab and greenhouse tests could be used to pinpoint the causes of problems observed in the field, while landscape level studies are required to understand the interaction with environmental variables (soils, climate, other species) and provide proof of concept / ability / success. Participants provided some context for revising policies and then provided specific changes that are required to improve efficiency and effectiveness of shrub reclamation.

In Session 4, participants suggested that a *shrub research roadmap* be developed (an alternative for a broader revegetation roadmap was also suggested). The roadmap would begin with a compilation of existing knowledge which would lead to development of an Action Plan. A team would have to be established to steer development of the roadmap and to secure funding; similarly a home for the project would be required – COSIA, OSRIN or CEMA were suggested as potential homes.

Some key projects suggested to be included in the Action Plan are:

- A gap analysis (flowing from the compilation of existing knowledge)
- Recommendation to government of policy changes necessary to support effective and efficient use of shrubs for reclamation

- Confirmation of reclamation goals and criteria relative to shrubs to allow for focused research and development work
- Retrospective analysis of existing reclaimed sites
- Best Management Practices for shrub use (collection, propagule management, deployment)
- An evaluation of the feasibility, location(s) and costs of seed orchards / stoolbeds
- A shrub monitoring program, including protocols that all operators will follow to ensure a common set of data
- Establishing a system to share existing and developing knowledge and coordinate future work
- Inventory of experts who can / will share knowledge
- Identification of training needs, and development and deployment of training programs
- Review the role of the Oil Sands Vegetation Cooperative, particularly if the rules governing plant and seed collection and movement are changed

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3.1.11 *Oil Sands Terrestrial Habitat and Risk Modeling for Disturbance and Reclamation (Phase I) – Dr. Clive Welham, FORRx Consulting Inc.*

Report: Welham, C., 2010. Oil Sands Terrestrial Habitat and Risk Modeling for Disturbance and Reclamation – Phase I Report. OSRIN Report No. TR-8. 109 pp. http://hdl.handle.net/10402/era.22567

Abstract: The overall objective of this project is to develop a framework that integrates risk management and strategic decision-making to evaluate the impact of disturbance (natural and industrial) on ecosystem products and services, and on habitat availability for terrestrial species in Alberta's Lower Athabasca planning region. This will include an evaluation of the impact of disturbance (natural disturbance due to insect outbreaks, fire and wind, as well as other industrial and agricultural disturbances), conservation, and reclamation activities associated with oil sands development both at the lease and regional levels.

The project will be conducted in three phases. Each phase is sequential such that its results and conclusions represent the foundation for the subsequent work. In this way, project investment and outcomes can be realized incrementally. Four scenarios will be incorporated into the overall project. These include scenarios constituting a basecase analysis, climate change, mine development plans, and regional development plans. The basecase scenario is a series of outcomes derived with no consideration for future climate change. The importance of the basecase is that it represents the null condition and thus provides a context for comparing the relative impact of different climate change scenarios (the focus of subsequent project activities).

The basecase scenario was the main focus of the work conducted in Phase I, and is comprised of a dendrochronology study of the relationship between climate and tree growth in the sub-boreal region that encompasses oil sands mining, an aspatial analysis of habitat suitability for 10 wildlife species in relation to reclamation activities on the Kearl Lake mine, and a risk analysis of the potential for development of water stress in young reclamation plantations at the Kearl Lake mine. The report begins with an introductory chapter that defines core concepts and project objectives.

Dendrochronology

The dendrochronology work examined the relationship between climate and tree growth (specifically ring width) for four species (white spruce – *Picea glauca*, black spruce – *Picea mariana*, jack pine – *Pinus banksiana*, and trembling aspen – *Populus tremuloides*) in the sub-boreal forests of western Canada (Alberta and Saskatchewan). A review of on-line and literature sources was used to identify tree core collections from the region. A total of 29 chronologies were identified that matched a set of suitability criteria: 18 chronologies for white spruce, 8 for jack pine, 2 for black spruce and 1 for trembling aspen. In addition, 9 aspen chronologies were analyzed from cores collected within the region. Each core series was used to date tree rings by year of growth and to create master chronologies of ring width over the previous 75 years (1935 to 2009). Residual chronologies were generated by standardizing and detrending master chronologies to remove non-climate-related influences on growth. These residual chronologies were then correlated to one or more of 25 climate-related variables derived from climate records obtained from nearby weather stations. Results indicate that radial growth of white spruce was limited by current year water stress; significant relationships were found between radial growth and growing season precipitation and summer temperatures. Similar results were found for jack pine, but no conclusive results were found for trembling aspen or black spruce. Subsequent work will be required to (a) add additional data sources, particularly for aspen, and (b) to determine whether additional climate relationships may better explain ring chronologies.

Habitat suitability analysis

Habitat suitability indices (HSIs) were calculated from equations for 10 boreal forest wildlife species (moose, black bear, snowshoe hare, lynx, red-backed vole, fisher, Cape May warbler, ruffed grouse, pileated woodpecker, and northern goshawk) in natural forests and within reclamation plans developed as part of the Kearl Lake mine. Input values for each index were derived from output generated from the ecosystem simulation model, FORECAST. The development of each index was calculated from the initiation of reclamation through to mine closure as per practices described in the Kearl Lake Environmental Impact Assessment (EIA). It should be noted that for some species, the HSI includes parameters with a spatial component, the latter of which requires calculation of one or more landscape metrics. For present purposes, HSIs were calculated for the 10 species without including spatial metrics. In practical terms, these HSIs then represent the most optimistic scenarios for habitat development since the inclusions of spatial metrics only serves to reduce habitat suitability (though in some cases, the HSI may remain unchanged).

Specific objectives were as follows:

- Review of habitat suitability models that may be applicable to Alberta boreal forests.
- Identify variables used in the habitat suitability models that can be simulated with the FORECAST model.
- Simulate the reclamation prescriptions described in the Kearl Lake EIA documents with FORECAST and generate output suitable for populating each habitat suitability model.
- Generate habitat suitability indices (HSIs) for 10 wildlife species (identified from the review) on the Kearl lake mine site and compare and contrast the temporal development of habitat from reclamation initiation to mine closure.

Conclusions were:

- There is a 37-year window following mine operation when upland habitat suitability is very poor on the mine footprint (an area that encompasses almost 30,000 ha).
- Habitat suitability recovers relatively quickly thereafter; 50 years after mine operation, 4 out of 10 species have a 100 % suitability index, and this increases to 9 out of 10 species 55 years after mine operation.
- The overall quality and pattern of recovery in habitat suitability depends on how much upland is reclaimed relative to the original (pre-mining) landscape.
- Deviations in the post-mining distribution of ecosite phases relative to the pre-mining landscape could have significant implications for the habitat suitability of particular species, either positively (more habitat is created) or negatively.
- The broad variation among species in their HSI values suggests that reclamation practices could be targeted towards the habitat requirements of one particular wildlife species by preferentially reclaiming more favourable ecosite phases. Conversely, a broad range of ecosite phases is necessary to promote a higher degree of biodiversity on the reclaimed landscape.
- When habitat recovery rates on reclaimed sites are considered in conjunction with the overall mine footprint, it suggests that the negative impact of the operation is not trivial with respect to habitat loss.

A risk analysis of the potential development of water stress in young reclamation plantations

The development of ecologically viable reclamation strategies and methodologies in the oil sands region can be a difficult undertaking considering the logistical challenges of constructing soil covers capable of providing both the hydrological and nutritional characteristics required for the establishment of self-sustaining, productive forest ecosystems. To examine the potential for the development of water stress in proposed reclamation plantations within the Kearl Lake mining area, a risk analysis was conducted for different species and ecosite combinations using the stand-level forest hydrology model ForWaDy. The risk analysis was designed to evaluate the probability of high levels of water stress developing in young plantations of white spruce, trembling aspen, and jack pine established on different ecosites as a function of soil texture and slope position. Each species and soil type combination was simulated for a 25-year period using historical climate data from the Fort McMurray weather station. Annual summaries of simulated water stress (expressed as a Transpiration Deficit Index; TDI) during the growing season were used to derive probabilities of exceeding a range of water stress thresholds.

Spruce was the species most likely to experience high TDI levels (greater than 0.3). In addition, it was the only species to reach TDI levels greater than 0.6 during the 25-year simulation period. Jack pine, in contrast, was the least likely to experience high TDI levels and did not exceed levels of 0.5 during any year; the remaining species were intermediate between the spruce and pine. The probability of exceeding TDI thresholds was consistently greater in an a-b ecosite grouping (representing dry, nutrient poor sites) relative to a d-e grouping (moist, nutrient-rich sites). Differences between the two ecosite groupings were relatively small, however. The difference would have been greater if not for the 50 cm peat layer that is applied to each site as a rooting substrate, and which alone constitutes 70% to 80% of the water holding capacity of the total soil profile.

The probabilities reported here are based on the simulated response of the tree–soil combinations to the past 25 years of climate data (1982 - 2006). These years reflect the current climate but are not likely to be representative of future climate conditions predicted for the region from Global Circulation Models. An exploration of the impact of climate change on water stress and its implications for overall growth and the associated development of structural habitat elements will be conducted in Phase II of the project.

The report concludes with a brief description of the next steps in the project.

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3.1.12 *Oil Sands Terrestrial Habitat and Risk Modeling for Disturbance and Reclamation (Phase II) – Dr. Clive Welham, FORRx Consulting Inc.*

Report: Welham, C. and B. Seely, 2011. Oil Sands Terrestrial Habitat and Risk Modelling for Disturbance and Reclamation – Phase II Report. OSRIN Report No. TR-15. 93 pp. http://hdl.handle.net/10402/era.24547

Abstract: The overall objective of this project is to develop a framework that integrates risk management and strategic decision-making to evaluate the impact of disturbance (natural and industrial) on ecosystem products and services, and on habitat availability for terrestrial species in Alberta's Lower Athabasca planning region. This includes an evaluation of the impact of disturbance, conservation, and reclamation activities associated with oil sands development both at the lease and regional levels. The principal objective in Phase II is an evaluation of the impact of climate and climate change on reclamation success, as compared to the basecase analysis (no climate-related impacts) conducted in Phase I.

Chapter 2, describes the calibration and testing of a tree ring model for the three major tree species represented in the Alberta Oil Sands region, white spruce (*Picea glauca*), trembling aspen (*Populus tremuloides*) and jack pine (*Pinus banksiana*). The model simulates the relationship between annual sapwood production (expressed as a ring width index), mean daily temperature and available soil moisture. Simulated ring width increments were regressed against the measured annual ring width index to evaluate the performance of the model. The tree ring model was able to successfully predict patterns in ring chronologies for white spruce and jack pine. Indeed, the explanatory capability of the model exceeded that which is typical from studies linking ring width to simple climate variables. In the case of aspen, results were less definitive. This study thus provides evidence for the applicability of this approach and it also highlights the utility of incorporating a few basic ecophysiological principles into models of tree growth.

Chapter 3 describes the characteristics of five Global Circulation Models and the Alberta Climate Model that are used to simulate climate change in the rest of the report.

In Chapter 4, the Tree and Climate Assessment (TACA) model is used to assess the regeneration potential of three boreal tree species (white spruce *Picea glauca*, trembling aspen *Populus tremuloides* and jack pine *Pinus banksiana*) on different soil types in northern Alberta. Model results indicate that under most scenarios, regeneration by all species is generally favoured by the warmer temperatures and higher annual precipitation predicted under climate change. One striking exception is the most severe emission scenario, where very warm conditions are a significant driver of moisture limitations and a low to non-existent regeneration potential. In the case of aspen, its ability to reproduce vegetatively improves the adaptive capacity of this species; clones can regenerate and persist by re-sprouting while maintaining their colonizing ability and potentially enhancing their distribution through seed-based regeneration. As a model that incorporates many of the biophysical variables important to tree regeneration, TACA is a suitable tool for making realistic projections of the impact of climate and climate change on the regeneration potential of the boreal tree species in northern Alberta.

Chapter 5 evaluates future ecosystem development in jack pine, aspen and white spruce with the FORECAST Climate model after incorporating the five climate change scenarios developed in Chapter 3. Stands initiated under current climatic conditions (in year 2011) are predicted to experience enhanced long-term productivity (to year 2111) under a changing climate regime, as compared with the growth that would have occurred if historical climatic conditions been maintained over the next 100 years. Although there was a substantial range among GCM scenarios in their projections of stemwood growth, the minimum projection was always greater than that derived from the historical climate data. In general, forest productivity in northern latitudes is temperature-limited. Model output suggests that tree productivity in the region may be enhanced through much of the 21st century as a result of improvement in the thermal regime (longer growing seasons, warmer soil, increased decomposition) and potentially an overall increase in available moisture, that more than compensates for any negative impact associated with growing season moisture limitations. In general, understory plant communities were negatively affected by the projected increase in overstory productivity under climate change.

Model projections indicated that habitat suitability under climate change would be improved overall, relative to values derived using the historical climate regime. The greatest improvement was for the d1 (aspen) ecosite and the least in the d3 (white spruce) ecosite.

Taken together, the model results suggest a number of management responses within the context of oil sands reclamation that can reduce risk, and help mitigate carbon emissions and retain habitat features, at least for some species. These are:

1. **Minimize the forest cover removed as part of mine operations.** Retention of forest cover improves the carbon balance and, depending on its areal extent and spatial configuration, can also serve as refugia for wildlife on the mine footprint.
2. **Return forest cover as soon as is practicable.** Forest productivity under climate change is enhanced, which will translate into higher carbon sequestration and improved habitat suitability as compared to the reference case (the historical climate regime). Returning forest cover quickly thus serves to leverage the benefits from improved productivity.
3. **Expand forest carbon sinks to promote carbon storage and development of habitat attributes.** Adding fertilizer annually for 5 to 10 years after planting, particularly on poor sites, will promote both tree and understory productivity, and thus carbon storage and development of habitat attributes. Retaining and adding slash and other dead organic matter after land clearing will also increase carbon stores (at least temporarily) but more importantly create valuable habitat.
4. **Encourage species mixtures over monoculture plantations.** Conifer monocultures and extensive tracts of aspen-dominated forests are vulnerable to outbreaks of insect defoliation and bark beetles. Planting tree species in mixtures or at the very least, reducing the areal extent of monocultures may help mitigate risk, enhance forest resilience, and/or prevent large-scale pathogen outbreaks.
5. **Increase protection measures.** Mine operators should develop and implement regular monitoring programs on their reclaimed areas to identify potential threats to stand health before they become unmanageable.
6. **Enhance fire suppression capability.** An increased risk of forest fires (both in frequency and severity) is predicted to occur with climate change. This could result in significantly greater releases of carbon as material is consumed, but can also generate rapid and pronounced shifts in community composition.

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3.1.13 *Oil Sands Terrestrial Habitat and Risk Modeling for Disturbance and Reclamation (Phase III) – Dr. Clive Welham, University of British Columbia*

Report: Welham, C. and B. Seely, 2013. Oil Sands Terrestrial Habitat and Risk Modelling for Disturbance and Reclamation: The Impact of Climate Change on Tree Regeneration and Productivity – Phase III Report. OSRIN Report No. TR-36. 65 pp. http://hdl.handle.net/10402/era.31900

Abstract: The overall objective of this project is to develop a framework that integrates risk management and strategic decision-making to evaluate the impact of disturbance (natural and industrial) on ecosystem products and services, and on habitat availability for terrestrial species in Alberta's Lower Athabasca planning region. This also includes an evaluation of conservation, and reclamation activities associated with oil sands development both at the lease and regional levels.

The project has been conducted in phases. Each phase is sequential such that its results and conclusions represented the foundation for subsequent work. This report summarizes activities conducted as part of Phase III, consisting of the following: (1) Model projections of tree regeneration under climate change on actual oil sands reclamation materials, and (2) A comprehensive model analysis of the risks to ecosystem productivity from climate change as a consequence of the impact of moisture stress on tree mortality.

Model projections of plant regeneration under climate change on actual oil sands reclamation materials

Six climate change scenarios for Alberta were selected that encompassed a range of predictions in future temperature and precipitation change. The tree and climate assessment (TACA) model was calibrated for reclaimed sites that varied in their soil moisture regimes (from xeric to subhygric) and three natural sites, High Level (subxeric), Calling Lake (mesic), and Fort Chipewyan (subhygric). TACA was used to predict regeneration probabilities on these sites for jack pine, aspen, and white spruce, in conjunction with the climate change scenarios.

A comparison between the natural sites and their corresponding moisture regimes on reclaimed sites showed little quantitative difference in predicted regeneration for High Level. Regeneration probabilities for Calling Lake and Fort Chipewyan, however, were lower than the corresponding moisture regimes on reclaimed sites (mesic and subhygric, respectively). The differences in the Calling Lake and Fort Chipewyan sites are largely a consequence of the fact that percolation rates were higher on natural versus the reclaimed sites. These results highlight the importance of assessing soil moisture regime using a variety of metrics.

Across climate periods, regeneration in this northern region was generally improved in jack pine and aspen because of the warming temperatures and in some scenarios, increases in annual precipitation, predicted under climate change. This was particularly the case in the wetter moisture regimes (submesic to subhygric) than the subxeric and xeric regimes, probably due to increases in growing season moisture deficits in the latter. Aspen regeneration from suckering had substantially greater predicted success than aspen regenerated from seed. Predicted trends in white spruce regeneration were in sharp contrast to the other species. Spruce regeneration was reduced substantially in future periods to the point where it was predicted to be less than 20% in subxeric and xeric moisture regimes. These results indicate that from a reclamation perspective, the impact of climate change on regeneration requires careful consideration of the tree species and its associated moisture regime.

Soil moisture regime generated pronounced differences in regeneration probabilities both within a given future time period, and across periods. As might be expected, regeneration was highest in the wettest moisture regime and declined as the moisture regime became drier. However, the difference between moisture regimes within a given time period also increased over time for all species. From the perspective of reclamation outcomes, these results suggest soil prescriptions should be developed and/or applied which generate moisture regimes that are submesic and wetter. Drier regimes (subxeric and xeric) appear to introduce a substantially greater average risk that revegetation success in a future climate may be compromised through regeneration failure.

How well might current reclamation prescriptions be expected to perform under climate change with respect to regeneration success? Overall, results suggest that no single set of prescriptions will be adequate to maintain the current suite of tree species common to the region. Nevertheless, current one-layer prescriptions seem adequate for maintaining pine and aspen regeneration, at least on average. Practices governing spruce, in contrast, should transition over the next several decades towards an emphasis on constructing two-layer prescriptions only, in an effort to minimize the risk of inadequate regeneration. This has important implications for mass balance calculations associated with soil amendment materials. In short, drier sites should focus on pine and possible aspen regeneration, and spruce on wetter sites.

For a risk management perspective, reclamation practices that generate the two wettest moisture regimes (mesic and subhygric) are most likely to result in successful outcomes, at least through the 2050s. Drier moisture regimes can have lower regeneration probabilities but results were often highly inconsistent across the climate scenarios; constructing covers that generate drier moisture regimes thus entails considerably more risk of inadequate regeneration. Although regeneration was high in the 2080s, in many moisture regimes uncertainty in model predictions was also high. However, because of this extended time frame, modifying current reclamation practices or planting prescriptions to mitigate this risk is not warranted. Taken together, results emphasize the point that the climate will continue to change and highlight the necessity for ongoing investment in this type of analysis to facilitate the process of continuous learning that can form the basis for adaptive management.

Analysis of risks to ecosystem productivity from climate change using FORECAST Climate

Drought is anticipated to be an increasingly limiting factor for plant productivity and survival in the Fort McMurray region. Regional climate data indicate that this trend has already begun with patterns of growing season moisture deficits increasing since the 1960s.

A new drought mortality function was developed and implemented within FORECAST Climate. In contrast to the threshold mortality approach employed in previous analyses, the new continuous function simulates drought mortality using a two-year running average of a species-specific moisture stress as a predictor of annual mortality. The 2-year running average is designed to capture the compounding effect of consecutive dry years. The amplitude of the function curve was fitted to historical climate data for each species so that mortality rates were consistent with empirical observations of actual mortality events. Two different mortality curves (low and high) were simulated for each tree species to explore the sensitivity of the model to assumptions regarding tree susceptibility to drought stress. To simulate the effects of a changing climate, five climate-change and associated emissions scenarios were utilized, and one scenario representing the historical climate regime. Simulations were conducted for ecosites dominated by jack pine (ecosite a1), aspen (d1), and white spruce (d3).

Jack pine showed very little mortality under the historical climate regime at either index of drought sensitivity. In the case of aspen (ecosite d1) and spruce (ecosite d3), historical drought-related mortality events were not uncommon in the simulations, consistent with empirical data.

Projections of future climate conditions generated mixed results in terms of mortality, depending on the emission scenario. With the exception of A1FI, all other emission scenarios triggered mortality below historical conditions at various points in the simulation. Given that primary productivity at high latitudes is temperature limited, a warming climate thus has the potential to improve survival under some circumstances, though not necessarily on sites where drought is already problematic. Within a given species, the highest mortality almost always occurred under the A1FI emissions scenario. Though A1FI was considered a pessimistic outcome in terms of CO_2 emissions, current evidence indicates that, in fact, it may be close to reality.

Pine and spruce appear generally robust to drought conditions at least over the next several decades, regardless of the climate regime. Mortality tended to increase thereafter as the simulation years got longer (i.e., later in the century). In absolute terms, pine is projected to have the lowest overall drought-related mortality (the exception being mortality under the A1FI emission scenario) while spruce is projected to have the highest mortality, particularly late in the century. Aspen showed a small increase in mortality over time beginning in the first decade of the simulations.

The Climate Response Index (CRI) is a metric calculated in FORECAST Climate that integrates the impact of temperature and precipitation. Similarly, the decomposition response index (DRI) links decomposition (i.e., nutrient availability) to temperature and moisture. Both indices thus serve as proxy measures of climate-related growth conditions. The A1FI scenario, by example, always generated higher CRI and DRI values than occur under historical climate conditions. Nevertheless, assumptions regarding tree sensitivity to drought stress had a significant impact on volume production and its relation to climate change. When the mortality rate was low (i.e., species were robust to moisture stress), volume production under climate change always exceeded that projected under the historical climate regime. If species are less tolerant of moisture stress (i.e., the mortality rate function was high) climate change will have a negative impact on stand-level productivity later in the century, though how much depends on the particular species and a given emissions scenario.

Significant reductions in productive capacity from climate-driven mortality threaten to destabilize ecosystems beyond their resilient capacity. One feature that would serve to promote resilience by avoiding drought stress is to ensure the rooting zone possesses adequate available water holding capacity. This can be accomplished by ensuring capping materials have higher organic matter content, are not predominantly coarse textured, and of sufficient depth. Layering of capping materials to generate textural breaks also serves to increase moisture storage, at least temporarily. Another important feature in creating resilience is to properly match tree species to their edatopic position. Aspen, and particularly spruce, occupy wetter positions on the edatopic grid. For the most part, these species are more prone to drought than pine. It is important then to ensure they are not planted on sites that may become marginal in terms of available moisture. In that respect, another consideration is to actively modify planting prescriptions in anticipation of a drier climate. Conceptually, this approach is based on the assumption a given soil moisture regime will for all intents and purposes transition to a drier edatopic position with further climate warming.

In Europe, mitigative activities against climate change at the stand level are focusing on the regeneration phase. This is because a well-established plant population will have better prospects for surviving the vagaries of future (and largely uncertain) climate conditions and the fact little can be done to affect survival in stands that are mature today. Hence, one approach is to increase the genetic or species diversity in seeded and planted stands. This can be accomplished with traditional tree-breeding programs (termed provenance trials) though molecular genetics techniques have been developed that significantly reduce the time and resources needed for the selection process. Other possible silvicultural measures to promote establishment and maintenance of desired communities include moving up the planting season to take advantage of earlier spring conditions, using containerized stock to reduce drought risk, enhancing drought tolerance by employing seedlings with higher root:shoot ratios, and reduced spacing to increase recovery after dry periods.

Quantitative models, such as TACA and FORECAST Climate, can project forest responses and the goods and services those forests provide to a range of future climate change scenarios. Predictions made using these climate-based models need to inform best management practices and can be coupled to the continuous learning that forms the basis of an adaptive management process, thereby reducing the uncertainty associated with reclamation decisions.

The report closes with conclusions and associated recommendations, and a final section describing potential next steps.

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3.1.14 *Oil Sands Wetlands Assessment Training Video – Brenda Rooney, Rooney Productions*

Rooney Productions, 2012. *Assessment Methods for Oil Sands Reclamation Marshes*. OSRIN Video No. V-1. 20 minutes. Also available on the University of Alberta You Tube Channel (recommended approach).

Rooney Productions, 2012. *Assessment Methods for Oil Sands Reclamation Marshes*. OSRIN Video No. V-1. Nine-part mobile device version. Also available on the University of Alberta You Tube Channel (link to Part 1 - recommended approach).

Oil sands mining closure plans call for the construction of wetlands as part of mine reclamation. Extensive work, funded in part by the Cumulative Environmental Management Association, has been devoted to developing sophisticated tools for evaluating shallow open water marshes within this context. These tools use environmental and biological measurements to assess the condition of individual wetlands, providing integrative scores that will help industry track wetland development and may assist the government in reaching certification decisions. These tools have undergone rigorous calibration and validation, have passed the peer review process, and are published in the scientific literature. In other words, they provide a scientifically sound and defensible approach to wetland assessment in the context of oil sands reclamation. However, to facilitate their implementation, a detailed assessment handbook and training video are necessary.

Alberta Innovates – Energy and Environment Solutions is funding the creation of a handbook that details the field collection, sample processing, and analysis methods broken down into easy to follow protocols. OSRIN is funding development of a video tutorial that will lay out the field sampling process from start to finish in easy-to-follow steps and will visually clarify how protocols should be enacted. This will help standardize otherwise subjective decisions, like how to determine if a plant lies within a floristic quadrat. It will also provide practice quadrats to help train field workers' eyes to quantify the relative abundance of different plants. The video will be optimized to play on a handheld device, enabling practitioners to consult the video in the field and to stream it anywhere with cell phone reception.

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3.1.15 *Potential Impacts of Beavers on Oil Sands Reclamation Success – Dr. Brian Eaton, Alberta Innovates – Technology Futures*

Report: Eaton, B., T. Muhly, J. Fisher and S-L. Chai, 2013. Potential Impacts of Beaver on Oil Sands Reclamation Success – an Analysis of Available Literature. OSRIN Report No. TR-37. 65 pp. http://hdl.handle.net/10402/era.32764

Abstract: The North American beaver (*Castor canadensis*) is a large semi-aquatic rodent that has played a central role in shaping the Canadian boreal landscape, and colonial Canadian history. Exploitation of North American beaver populations to supply the European hat industry spurred the westward expansion of European explorers and traders into the continental interior. With intensive unregulated harvest, beavers virtually disappeared across much of their range; though populations are recovering, the species is only about 10% as abundant as it was before the fur trade took its toll. As a result, much of the recent ecological history of the Canadian boreal forest has occurred in the absence of this keystone ecosystem engineer, and the ecological state that we perceive as natural is in many regions quite different than it was a century ago.

Beavers, while playing an important role in structuring streams and wetlands by altering vegetation communities and water flow patterns, may also affect human structures. In the mineable oil sands region of northeastern Alberta, much of the landscape will be impacted by mining. Mine sites will have to be reclaimed, and those reclaimed sites will consist of engineered landforms (including water bodies and waterways); the long-term hydrological and ecological function of those sites may be vulnerable to beaver activity. In an effort to determine if approaches exist that could manage the risk of beavers colonizing and negatively impacting reclaimed sites, we performed an extensive literature search and analysis. Our objective was to examine characteristics of beaver ecology that might potentially impact reclamation plans, and to identify possible methods to mitigate those impacts. We also include information on traditional use, historical abundance, and current abundance in the mineable oil sands region to provide important historical and ecological context. Although beavers inhabit a range of aquatic habitats, the focus of our review is on watercourses that could be dammed by beavers. Of the aquatic habitats which will be constructed during reclamation, these systems are probably the most vulnerable to impacts from beaver activity. Note, however, that inlet and outflow streams from lakes may be vulnerable to beaver activity, which could impact the performance of constructed lakes in a variety of ways.

Beavers alter stream form and function, create wetlands, and change vegetation patterns. The most important predictor of beaver occurrence is stream gradient, with low gradients being associated with higher beaver activity. Stream depth and width, soil drainage, and stream substrate are also important. Although beavers may also respond to vegetation factors, such as tree or shrub species and density, hydrological factors are more important predictors of beaver occupancy of a site.

The primary forage preferred by beavers includes deciduous tree and shrub species. Aspen (*Populous tremuloides*) is the species most preferred by beaver, and is a common component of reclamation plantings and natural recolonization of reclamation sites in the oil sands region. Beavers are central-place foragers, meaning foraging is concentrated around a central home base. They typically harvest deciduous trees and shrubs up to 60 m or more from the water, but most harvest occurs less than 30 to 40 m from the water's edge. Predation (and predation risk) restricts the size of beavers' foraging areas, and may also regulate their population size. Management of wolf populations to limit predation on caribou in northeastern Alberta may have significant indirect effects on beaver abundance and distribution by releasing them from predation pressure.

The boreal forest ecosystem of Canada evolved over millennia with the beaver as a keystone species altering hydrological systems, creating vast areas of wetlands and beaver meadows, changing vegetation communities and modifying geomorphological processes. Reclamation of functional ecosystems in the region must therefore integrate beavers and their engineered structures. The most ecologically- and cost-effective approach is to design reclaimed areas with the objective of including beaver, but directing beaver activity to areas away from vulnerable reclamation structures. Ecological function requires the presence of beaver on the post-reclamation landscape, and the species is important to First Nations peoples and other trappers in the area. Although beaver abundance can be expected to increase in the area after reclamation, their activities will result in the replacement of existing vegetation with species of lower nutritional quality to beaver (conifer trees). This is expected to result in a beaver population decline and then stabilization over time. With beavers an integral component of the functional landscape, it is important to create "beaver exclusion zones" to ensure that the impact of the species is diverted to areas where beaver activity does not damage reclamation structures.

There are very few existing studies of beaver impacts to reclaimed areas. Incorporating ecologically-based strategies for keeping beaver density low in sensitive areas at the outset of a reclamation project, and then monitoring the effectiveness of that strategy, is the best advice that can be derived from our analysis of the existing literature. Beavers could be discouraged from settling at a site by creating streams with steep gradients (>10%) that are wide and deep enough to ensure substantial water flows, are armoured with rock or cobble bottoms, and are bordered by coniferous tree species and/or grass and sedge species. Trees should be planted at high density to prevent growth of shrubs and deciduous trees in the understory, as these are preferred by beaver. Deciduous vegetation should not be planted during reclamation near sites where beavers are to be excluded, and it may be necessary to remove existing deciduous trees and shrubs and replace them with conifers, grasses and sedges in these areas. Although planting specific types of vegetation may be used to discourage beavers from settling a certain area in the short term, natural succession could eventually result in other vegetation communities attractive to beavers. Therefore, unless long-term vegetation management is envisioned, reclamation plans should not rely on using vegetation to dissuade beaver activity in sensitive areas alone, though this approach may be used in combination with other methods, especially in the few decades immediately following reclamation. Note that the goal is to plan for a maintenance-free environment in which ongoing beaver control is unnecessary, and the use of multiple strategies in tandem to guide beaver activity is more likely to achieve this goal.

More active, maintenance-intensive techniques could be used to limit the damage caused by beaver dams to sensitive areas. These techniques include lethal (e.g., kill trapping or shooting) and nonlethal (e.g., relocation) methods to reduce population density. However, these methods require constant effort, and can be expensive. Another approach is to manipulate water flow through existing beaver dams using pipe drainage systems; this allows the beaver dam to stay in place, while reducing the risk that it will trap enough water to be dangerous if the dam should fail. Again, however, these drainage systems require long-term maintenance.

One approach may be more sustainable in the long term and require less maintenance: minimize or maximize water flow through engineered channels, as beavers are less likely to use very low-flow and very high-flow watercourses. Note that beavers may still affect these channels, especially when population densities are high or other habitat is unavailable; however, the probability of beavers affecting very low-flow or high-flow channels is lower than for watercourses with more moderate flows. Creating several dispersed low-flow channels may make an area less desirable to beavers compared to a single moderate flow channel. Similarly, multiple low- to moderate-flow channels could be created, with some having characteristics that attract beavers ("decoys") and others that do not ("exclusions"), allowing water flow to continue through some channels even in the presence of beavers. "Pre-dam" fences can be installed on decoy streams to create a structure to encourage beavers to occupy a site where damage is not a concern. Discharge could be controlled by regulating water flow through exclusion streams that are not dammed, or by installing flow devices though dams on decoy streams. A similar approach might be used on culverts that allow streams to flow beneath roadways; flow devices could be used proactively at these sites, and/or oversized culverts could be installed to allow maintenance of the natural width of the stream channel and reduce the noise of running water, which attracts beaver activity.

Although many different landforms on the reclaimed landscape may be vulnerable to beaver activity, a few are considered critical areas where beaver impacts must be controlled, including the outlets of lakes, side-hill drainage systems, and constructed peatlands. Beaver activity at the outlet of constructed lakes could cause instability in containment structures, negatively affect littoral and riparian zones around the lake, and increase the probability of catastrophic outburst flooding. Damming of side-hill drainage systems could cause stream avulsion and routing of water flow into a new pathway not engineered for a stream, causing increased erosion. Flooding of constructed peatlands could convert them to open-water systems, thereby subverting their intended ecological function. These critical areas should be protected from beaver activities, while other areas should be designed to accommodate this important species.

In practice, several different approaches – tailored to specific situations and landforms – will be necessary to develop and implement plans that accommodate beavers as a part of the post-reclamation landscape. As so few data exist to inform effective reclamation in the presence of beavers, all of the methods we suggest carry an unknown degree of risk. This risk can be decreased in the future by adapting methods based on observed effectiveness. We recommend implementing a research and adaptive management program on the influence of beavers on reclamation within the context of oil sands reclamation in northeast Alberta. Lack of existing information, particularly in northeast Alberta, illustrates the need to implement research that documents the positive and negative influence of beavers on reclamation sites and tests alternative methods to prevent negative and support positive influences. Otherwise reclamation strategies will be ad-hoc and tenuous, with a mixed success rate. A research and monitoring program would ideally contribute to a standardized strategic approach to mitigating negative beaver influences on reclamation of watercourses in the oil sands region.

Beavers are, to a certain extent, unpredictable. No single approach will guarantee that a site will be unaffected by beaver activity. We suggest that multiple management approaches be simultaneously implemented at sites that are particularly vulnerable or critical for the functioning of the reclaimed landscape (e.g., outlet streams from constructed lakes). It is impossible to predict all eventualities, as the character of the reclaimed landscape will change over time due to successional processes, fire, global climate change, and resource extraction. The information we provide is the best available based on limited current knowledge, and provides the best chance for minimizing risk while accommodating this keystone species. Ultimately, the presence of beavers on reclaimed oil sands leases will increase biodiversity, enhance ecosystem goods and services, and assist in developing ecosystems that are consistent with natural systems in the boreal region.

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3.1.16 *Preliminary Watershed Hydrology and Chemical Export Model for Reclaimed Oil Sands Sites – Dr. Gordon Putz, University of Saskatchewan*

Report: Watson, B.M. and G. Putz, 2013. Preliminary Watershed Hydrology Model for Reclaimed Oil Sands Sites. OSRIN Report No. TR-39. 193 pp. http://hdl.handle.net/10402/era.34250

Abstract: The main goal of this research project was to take the first steps towards development of an integrated hydrologic and water quality model to support oil sands mine reclamation efforts in Alberta. The model utilized in this study is a modified version of the Soil and Water Assessment Tool (SWAT), which has been called $SWAT_{BF}$. This report provides a detailed description of the $SWAT_{BF}$ model, a list of the key parameters (and their ranges) utilized in $SWAT_{BF}$ and the availability of data sets in the oil sands geographic area to set up and operate $SWAT_{BF}$. Furthermore, an application of the model to five regional watersheds and an industrial reclaimed watershed is described and discussed. Recommendations for further research directions are also provided.

Currently there are few high quality data sets available for reclaimed watersheds in the oil sands region that can be used to stringently test the performance of $SWAT_{BF}$ or similar models. Although several good quality data sets do exist in the oil sands region, they were not available to the authors of this report for testing purposes. The model was applied to five regional watersheds in the oil sands geographic area for the period 1976 to 1993. The overall performance of the model for predicting the long-term water yield from these regional watersheds was deemed to be satisfactory based upon statistical comparisons of predicted and measured streamflow. The modelling results for the regional watersheds were encouraging and demonstrate that $SWAT_{BF}$ has the potential to be utilized as a practical tool for conducting hydrologic assessments in the oil sands geographic area. It may also be suitable for water quality modelling purposes following future data collection. Limited data sets were available from the Wapisiw Lookout reclaimed watershed, which was constructed by Suncor Energy Inc. Using runoff estimates derived from changes in the water level of the Wapisiw wetland, it was possible to test calibrate $SWAT_{BF}$ for 2011 and 2012. The results achieved for 2011 were deemed to be good. It is recommended that further testing of the model on reclaimed watersheds be undertaken using high quality data sets. The data that are scheduled to be collected from the Wapisiw Lookout watershed by the Forest Watershed and Riparian Disturbance (FORWARD) Project will be used to further improve the performance of $SWAT_{BF}$ and extend its capabilities to chemical transport. However, it will take several years to collect the data sets necessary to further develop $SWAT_{BF}$ into a useful management tool to support reclamation efforts in the oil sands. Several proprietary data sets exist in the oil sands that, if made available, may expedite this research effort. The authors have made several recommendations on how future research efforts should proceed to aid and further develop the capabilities of $SWAT_{BF}$ for reclaimed watersheds in the oil sands region.

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3.1.17 *Reclamation Alternatives Dialogue Assessment and Design – Keith Jones, Innovation Expedition Consulting Inc.*

In this first phase of the Reclamation Challenge Dialog project in 4.4.1 above, the consultants worked with a Committee to develop the scope for a Challenge Dialog and prepared a first draft of the Challenge Paper.

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3.1.18 *Resiliency of Reclaimed Boreal Forest Landscapes – Matthew Pyper, University of Alberta*

Report: Pyper, M.P., C.B. Powter and T. Vinge, 2013. Summary of Resiliency of Reclaimed Boreal Forest Landscapes Seminar. OSRIN Report No. TR-30. 131 pp. http://hdl.handle.net/10402/era.30360

Abstract: Ecological resilience, first defined by Holling in 1973, can be broadly described as the capacity of an ecosystem to respond to a perturbation or disturbance by resisting damage and recovering quickly, but other authors have provided variations on this theme since 1973.

Ecological resilience is one potential measure of the goal of a self-sustaining ecosystem and is being considered for inclusion in the Cumulative Environmental Management Association's Criteria and Indicators Framework for assessing reclamation success in oil sands mines. For reclaimed lands to be considered self-sustaining they should respond to natural and anthropogenic disturbances in a similar manner to an analogous undisturbed landscape might respond to the same disturbances.

The University of Alberta's Department of Renewable Resources and the Oil Sands Research and Information Network jointly hosted a one-day seminar on January 22, 2013 at the University of Alberta to discuss the concept of ecological resiliency and how it can be applied to reclaimed landscapes. 108 people from a variety of organizations and technical interests attended the seminar.

There was general agreement amongst the presenters that resilience is a valuable topic to consider in reclamation planning. However, there was also agreement that implementing management systems based on resiliency would require a shift away from managing for consistency and single objectives (e.g., soil depth, stems/ha), to a system that embraces change and is focused on ensuring ecological processes are reintroduced to reclaimed landscapes (i.e., resiliency).

Some of the key ecological processes that were identified included: nutrient cycling and moisture availability; soil characteristics (e.g., pH, nutrient availability, propagules, soil biota, etc.); understory plant diversity (particularly when species are matched to the correct ecosite); presence of keystone species; and the proper construction of landforms which include slope, aspect and variability in their design.

The seminar was, by design, focused on providing information about the concept of ecological resilience and its potential application to land reclamation. The seminar participants recommended further sessions to bring the high-level concepts down to on-the-ground application.

There was also interest in holding a similar session in a year's time to provide more information and to focus on getting more technical detail, perhaps by focusing on specific research and implementation projects.

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3.1.19 *Review of Alternative Seed Packaging and Delivery Systems for Oil Sands Reclamation – Dr. Amanda Schoonmaker, Northern Alberta Institute of Technology*

Report: Schoonmaker, A., J-M. Sobze, E. Fraser, E. Marenholtz, A. Smreciu, C.B. Powter and M. Mckenzie, 2014. Alternative Native Boreal Seed and Plant Delivery Systems for Oil Sands Reclamation. OSRIN Report No. TR-55. 61 pp. http://hdl.handle.net/10402/era.40099

Abstract: The purpose of this document is to review traditional and alternative systems of seed and nursery stock treatment and delivery for use in oil sands reclamation. *Treatment systems* are considered those activities conducted prior to delivery to the field site while *delivery systems* include those activities involved in physically deploying the seed and plant material on the reclamation site. *Traditional systems* are those currently in use by the oil sands reclamation community, while *alternative systems* are those that have potential or promise for use following additional research.

The traditional systems included the following seed treatment and/or delivery systems: natural recovery, direct placement of topsoil, nursery production, planting of nursery stock and basic seed broadcasting. Alternative systems were drawn from a variety sources including: forest industry, agriculture, horticulture, mining, and home gardening. Results of peer-reviewed and non-reviewed scientific studies were included when available; in some cases anecdotal observations and unpublished results were presented. The following twelve alternative systems were identified: enhancement of soil stockpiles, seed priming, seed nano-coating, seed pelleting, multi-species propagation, Jiffy peat pellet®, biodegradable containers, disc seed driller and air seeders, harrowing, push-seeder, hydroseeding and aerial seeding.

It was clear that for all the alternative systems examined, further testing would be required on native boreal species in order to determine the effectiveness of the individual system. The following systems were highlighted:

1. Inclusion of targeted seed treatment systems, such as seed pelleting and priming, prior to delivering seeds is suggested as a promising area of future research and high application potential for field trials.
2. Seedling delivery from containers with multiple species (multi-species production) and biodegradable containers are most likely to have merit for specialized applications. However, multi-species production requires verification both at the level of identifying appropriate species mixtures, optimizing greenhouse production and quantification of field performance. Biodegradable containers are a suitable

option to further test on slow-growing species that are difficult to produce under standard greenhouse conditions in styroblocks.

3. Improving on basic seed broadcasting with the addition of a delivery system that would improve seed-soil contact is also suggested as beneficial. Harrowing is an easily deployable delivery system at small or large scales while large-scale delivery systems such as disc seeders and air seeders also had merit. The main drawbacks of these approaches are the necessity to conduct activities prior to roll back of woody materials on site, as well as any major surface site activities such as mounding or deep ripping. However, hydroseeding is also an option as it could be deployed following roll back of woody materials.
4. Aerial seeding may also have merit, for specific species (to be tested) on large reclamation areas as well as in situations with remote or difficult access.
5. Lastly, enhancement of soil stockpiles is an alternative delivery system that is closely analogous with the traditional delivery system and best practice of direct placement of topsoil. Reforestation of a soil stockpile, is in principle, a straightforward activity and could easily be implemented into broader revegetation and reclamation plans.

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3.1.20 *Role of Professional Expertise in Reclamation Certification – Roger Creasey, Terrain FX Inc.*

Report: Creasey, R., 2012. Workshop on the Information that Professionals Would Look for in Mineable Oil Sands Reclamation Certification. OSRIN Report No. TR-25. 52 pp. http://hdl.handle.net/10402/era.28331

Abstract: On June 18, 2012, the Oil Sands Research Information Network (OSRIN) convened a workshop to solicit the expert views from about 50 technical specialists from a variety of disciplines representing about 850 years of experience. The workshop, entitled Information That Professionals Would Look for in Mineable Oil Sands Reclamation Certification sought to document the field experience and "common sense" that a seasoned field specialist brings to the reclamation certification decision process.

The workshop was coordinated with the Reclamation Working Group (RWG) of the Cumulative Environmental Management Association (CEMA) to provide additional information in support of their Criteria and Indicators Framework project.

With some basic information on the hypothetical lands subject to a reclamation certificate application being considered, the groups were given three different scenarios to analyze from the viewpoint of their professional experience and technical knowledge:

Session One: You are going to visit a reclaimed oil sands mine site and decide if a reclamation certificate should be issued. You have only your five senses, experience and common sense to guide your decision.

- What positive and negative features do you look for?
- How confident (%) would you be that your decision is correct (i.e., mean and range)?

Session Two: Next, when you go onto the site you can bring one piece of equipment or one tool.

- What would you bring?
- What additional information will it provide for your assessment of the site?
- How much extra time (and time consuming logistics) would it add to your assessment of the site?
- Now how confident are you (%) in your assessment decisions (mean and range)?

Session Three: Next, in addition to your senses, experience, and the additional equipment you brought, you can ask for a report(s) regarding the site before the field assessment.

- What information would you want to see in the report/documents?
- Now, how confident are you (%) in your decision (mean and range)?

Session Four: For the final session in the workshop, the groups were asked to provide their comments on one of seven questions:

1. What do we need to know about contamination and remediation?
2. What advice can you give CEMA on criteria and the certification process?
3. Do expectations and process needs change depending on the reclamation goal(s)?
4. Do expectations and process needs change depending on when the site was reclaimed (i.e., older sites, currently reclaimed sites, sites reclaimed in the future)?
5. How long do we monitor for before applying for a reclamation certificate?
6. Do expectations and process needs change based on landform type (e.g., dump, tailings pond, Dedicated Disposal Area, plant site)?
7. What disciplines are missing from the discussion today?

The original intent of the workshop was to supplement the science-based reclamation certification criteria and indicators being developed by the Reclamation Working Group of the Cumulative Environmental Management Association with the knowledge and experience used by people with significant field experience. Although valuable suggestions about criteria were received, the discussions seemed to focus more on the information needs and process for assessing certification, suggesting the need for a Guide to the Reclamation Certification Process.

The workshop also sought to determine how confidence in decision making is affected by the use of field equipment/tools, and the value of background data and reports in increasing confidence. Given the extensive experience of the workshop participants, it was surprising to see how little confidence they had in using only their knowledge and experience to make reclamation certification decisions. Their confidence in making decisions increased somewhat if they were able to bring a piece of equipment into the field with them. If they were able to review a high quality report and supporting data from the site's historical file prior to going into the field their confidence increased substantially. This confirms the need for the CEMA RWG Criteria and

Indicators work and suggests the need for a Guide to Reclamation Certification Application Content.

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3.1.21 *Soil Microbiology as an Index of Oil Sands Reclamation Success – Dr. Sylvie Mercier Quideau, University of Alberta*

Report: Richardson, E., G. Walker, G. MacIntyre, S. Quideau, J.B. Dacks and S. Adl, 2014. Next-Generation Sequencing of Protists as a Measure of the Microbial Community in Oil Sand-Associated Soils. OSRIN Report No. TR-69. 26 pp. http://hdl.handle.net/10402/era.40343

Abstract: Soil plays a central role in the functioning of all terrestrial ecosystems. Among the many ecosystem services to which soil contributes are: purification and storage of water, sequestration of organic matter, nutrient cycling for plant growth, and conservation of healthy faunal and microbial populations. As such, soil quality is a key determinant of land reclamation success. Exploitation of the Athabasca oil sands deposit represents a massive land disturbance in Alberta. To date, over 600 km^2 of land has been disturbed by oil sands extraction. Following surface mining, reclamation efforts involve the reconstruction of entire landforms. Salvaged surface soils and near-surface geological materials are placed as a new soil cover on the reconstructed landscapes. The goal of reclamation in Alberta is to achieve land capability equivalent to that which existed prior to disturbance. Soil parameters that are currently used to examine reclamation success include chemical and physical attributes known to limit plant growth. Although it is essential to the functioning of these reconstructed ecosystems, soil biology is not yet included as part of the assessment.

This project characterized for the first time the biodiversity of soil microfaunal and mesofaunal populations on natural Athabasca oil sands sites. Specifically, we focused on soil protists and micro-invertebrates, as these largely bacteria-consuming organisms are responsible for much of the nutrient fluxes through the soil food web and have crucial bottom-up impact on animal and plant biodiversity.

The report addressed two issues. The first is to pilot the use of Next-Generation Sequencing (NGS) technology to establish an assessment of soil protist and invertebrate biodiversity in undisturbed soils as a starting point to identify bioindicators for future assessments of reclamation success. The second question was to assess the relative merits of using paired end 250 versus paired end 300 kits in the NGS protocol, as a technical note going forward.

We found that, for these samples, the paired end 250 kits and the protocols in place to use them were reliable and produced consistent datasets and were sufficient to capture the diversity within our samples. Therefore, the additional cost of the paired end 300 kit was not warranted for our needs and would not be adopted in future NGS studies for these organisms in this particular environment.

This first assessment of soil protist biodiversity revealed similar trends to those seen from other NGS studies of soils, with cercozoans and ciliates as obvious components of the biodiversity.

Further quantitative analysis is key to making any statements about the numerical abundance of any taxa in our samples. However, there are no obviously comparable samples available, with the closest analysis of boreal forest soil being performed with key differences in NGS technology, and the closest technically comparable sample coming from conifer soils in the southern USA. Although we have made as relevant comparisons as possible, to our knowledge this represents the first report of microbial eukaryotic biodiversity of undisturbed soil in the Athabasca region and is an important first step in assessing downstream efforts for soil reclamation and revegetation.

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3.1.22 *Soil Nitrogen Indicators for Land Reclamation – Dr. Scott Chang, University of Alberta*

Report: available through the Cumulative Environmental Management Association

Abstract: The lack of understanding of possible relationships between soil nitrogen (N) availability indices and forest productivity in the oil sands region of Alberta may adversely affect reclamation practices and the development of reclamation policy for the region. This project was designed to investigate the foregoing relationships on natural, undisturbed stands and to recommend the best soil N availability indicators to use to evaluate soil N for achieving the maximum site productivity and for long-term monitoring of soil and vegetation performance in the region.

Soil N availability indices evaluated in this project included several common field-based methods (available mineral N concentrations, in-situ N mineralization rates, potential N availability measured using the plant root simulator (PRS) probes) and laboratory-based measurements (extractable N, aerobic and anaerobic N mineralization rates). We attempted to correlate the above soil N availability indices with several forest productivity indices of three of the most common native tree species in this region. The measured forest productivity characteristics include foliar size of trees, annual tree growth ring width, and aboveground net primary productivity (ANPP). The results of our research showed that most N availability indices were correlated with productivity measurements in jack pine (*Pinus banksiana*) stands, while few N availability indices were correlated with productivity indices in trembling aspen (*Populus tremuloides*) and white spruce (*Picea glauca*) stands.

Based on those results, we conclude that jack pine forest productivity is most likely limited by N availability and thus there are tight relationships between many soil N availability indices and forest productivity; while for aspen and white spruce stands, factors controlling forest productivity may be more complex (such as co-limitation of water availability) and thus there are poor N availability-productivity relationships. We recommend that for jack pine stands, laboratory based aerobic and anaerobic mineralization rates are the most cost effective methods for measuring N availability while for aspen and white spruce stands the in-situ N mineralization rate is likely the most appropriate method to determine soil N availability, as that index gave the best relationship with stand productivity.

While this study helps to determine which method of measuring nitrogen availability is most appropriate for potential input to the land capability classification system (LCCS) for soil nutrient regime assessment, further research is need to evaluate the relationship between N availability indices and LCCS classes or reclamation performance, as the current project was conducted in natural forests and extrapolating into reclamation areas will be difficult without calibration between natural and reclamation sites; the natural sites in this study were used as an analog for future developed forest stands in the reclaimed area in the oil sands region.

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3.1.23 *Support Wetland Reclamation Conference – Dr. Dale Vitt*

OSRIN provided funds to support publication and distribution of report copes to the attendees of the March 25-27, 2010 conference organized by Dr. Dale Vitt on reclamation of wetland and forested sites.

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3.1.24 *What Constitutes Success for LFH Salvage and Replacement – Dr. Anne Naeth, University of Alberta*

Report: Naeth, M.A., S.R. Wilkinson, D.D. Mackenzie, H.A. Archibald and C.B. Powter, 2013. Potential of LFH Mineral Soil Mixes for Land Reclamation in Alberta. Oil Sands Research and Information Network, University of Alberta, School of Energy and the Environment, Edmonton, Alberta. OSRIN Report No. TR-35. 64 pp. http://hdl.handle.net/10402/era.31855

Abstract: LFH salvaged with small amounts of upper horizon mineral soil for land reclamation (hereafter LFH mineral soil mix) has proven to be an important source of seeds and vegetative propagules for forest plant communities. Until recently in Canada, LFH mineral soil mix was not selectively salvaged from upland forest sites prior to disturbance and was mainly incorporated with deeper mineral soil horizons or subsoil as part of conventional salvage and placement practices. The Alberta government is beginning to require oil sands and mountain and foothills coal mines to salvage and store this material separately from underlying mineral soil and subsoil for use in reclamation. The potential of LFH as a source of native propagules for revegetation of disturbed landscapes and a source of organic matter and nutrients in soil reclamation has not been widely tested. This report summarizes available literature on potential use of LFH material in Alberta and provides an analysis of the current state of knowledge and future directions.

Although donor soil seed banks have been successfully used as a revegetation technique on mine sites and land disturbances in other ecosystems for some time, only recently has research been conducted using forest LFH for mine revegetation in Alberta. Most of this research has been conducted on a small scale with few operational scale studies and a rigorous experimental approach is often lacking. Currently there are only a few peer reviewed publications on the use of LFH as a propagule source or reclamation soil in Canada.

Recent research shows LFH mineral soil mix is a good source of propagules for native and woody species that are not readily available commercially or by wild collection. Most plants in LFH mineral soil mix establish from seed and resultant communities have greater plant cover, more upland species and fewer non-native species than with traditional peat mineral soil mix used in oil sands mines. Stockpiling before placement reduces seed viability and species diversity, thus direct placement is recommended although stockpiling still results in more diverse and abundant plant communities than peat mineral soil mix. Placement depth has greater effect on plant community development than salvage depth. Thresholds for salvage and placement have not been determined and are dependent on donor soil texture, ecosite, topography, forest type and substrate placed on.

Besides using LFH mineral soil mix to revegetate disturbed landscapes, it can be used to improve soil quality. Compared to conventional peat mineral soil mixes in the oil sands, LFH mineral soil mix has a texture and pH more similar to natural forest and provides greater available phosphorus and potassium. Soil microbial activity and diversity is also greater which may lead to a more productive and resilient plant community in the long term.

Recent research on LFH mineral soil mix for forest reclamation has led to development of regulatory requirements. Short term research results (< 10 years) clearly show benefits of LFH mineral soil mix for reclamation. However, whether short term effects will persist with time and lead to a more natural, diverse and sustainable plant community than conventional reclamation techniques is unknown. Enhanced soil properties and native regeneration strongly suggest reclaimed communities are on a trajectory towards the structure and function of self-sustaining natural forest. By researching a few key operational and ecological questions, benefits of LFH mineral soil mix can be maximized and ongoing reclamation costs reduced.

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3.1.25 *Woody Debris Field Guide – Dr. Vic Lieffers, University of Alberta*

Report: Pyper, M. and T. Vinge, 2013. A Visual Guide to Handling Woody Materials for Forested Land Reclamation. OSRIN Report No. TR-31. 10 pp. http://hdl.handle.net/10402/era.30360

Abstract: In a short period of time, the conversation around handling woody materials – deadwood such as logs, branches and stumps – has shifted dramatically. From piling and burning, to mulching and now towards keeping 'whole logs' on sites. The changes have led to confusion and this guide is intended to provide clarity around wise use of woody materials in reclamation programs.

This guide is intended to answer the following questions:

- Why has there been a shift in how we manage woody materials?
- How can woody materials be managed effectively on sites?
- What do effective woody material applications look like?

Through this work, we hope to promote effective use of woody materials in an effort to encourage revegetation on industrial sites through the creation of microsites. For a more detailed look at managing woody materials see *Managing woody materials on industrial sites: Meeting economic, ecological and forest health goals through a collaborative approach* by Tim Vinge and Matthew Pyper.

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4 MONITORING ECOSYSTEM IMPACTS PROGRAM

This program focuses on components of a comprehensive, robust system in Alberta to monitor the effects of oil sands mining operations on ecosystem health – a system that is scientifically sound and has the confidence of the general public.

Project	Researcher
Active Projects	
PAH and Heavy Metal Content in Mammal Organs in the Mineable Oil Sands Region	Graham Knox, Alberta Innovates - Technology Futures
Completed Projects	
An Evaluation of Wireless Sensor Networks and their Potential Implementation to Monitor Environmental Variables at Oil Sands Sites	Dr. Arturo Sanchez-Azofeifa, University of Alberta
A Rapid Solution for Screening and Quantifying Targeted and Non-Targeted Analytes in Oil Sands Process Water and Natural Waters in the Athabasca Region	Dr. Jonathan Martin, University of Alberta
Assessment and Design of a Challenge Dialogue titled "What Constitutes Monitoring Adequacy in the Oil Sands Region?"	Doug James, Congruent Strategies
Assessment of Air Quality Remote Sensing Technology for Alberta's Oil Sands Region	Dr. Zaher Hashisho, University of Alberta
Characterizing the Organic Composition of Snow and Surface Water Across the Athabasca Region – Phase 2	Dr. Jean Birks, Alberta Innovates – Technology Futures
Dialogue on Monitoring and Information Reporting Adequacy	Doug James, Congruent Strategies
Evaluation of Community Level Physiological Profiling as a Means of Assessing Aquatic Ecosystem Health in the Oil Sands Region	Jim Davies, Alberta Innovates – Technology Futures
Instruments for Research on Air Quality Control and Characterization	Dr. Zaher Hashisho, University of Alberta
Inventory and Characterize the Monitoring and Reporting of Oil Sands Environmental Health	Eric Lott, EO Consulting

Project	Researcher
Isotope and Geochemical Tracers for Fingerprinting Process-Affected Waters in the Oil Sands Industry	Dr. John Gibson, Alberta Innovates – Technology Futures
Metrics for Assessing Fisheries Productivity of Oil Sands Compensation Lakes	Dr. Mark Poesch, University of Alberta
Microcosm Evaluation of CLPP in Oil Sands Process Affected Water	Dr. Jim Davies, Alberta Innovates - Technology Futures
Modeling and Assessing the Impact of Oil Sands Contaminants on Aquatic Food Webs	Dr. Mark Lewis, University of Alberta
Oil Sands Groundwater – Surface Water Interactions Workshop	OSRIN and Canadian Environmental Assessment Agency
Organic Footprint of Atmospheric Deposits: Snow and Surface Water Fingerprinting Across the Athabasca Region	Dr. Jean Birks, Alberta Innovates - Technology Futures
Potential to Use Wildlife as Monitors of Ecosystem Health and Sustainability in the Oil Sands Region	Dr. Judit Smits, University of Calgary
Surface Water – Groundwater Interactions in the Lower Athabasca Region	Melanie Dubois, Cumulative Environmental Management Association
Wild Plant and Soil Sampling in Support of Oil Sands Contaminant Load Assessment	Dr. Cindy Jardine, University of Alberta

4.1 Active Projects

4.1.1 *PAH and Heavy Metal Content in Mammal Organs in the Mineable Oil Sands Region – Graham Knox, Alberta Innovates - Technology Futures*

Liver and kidney tissues from mammals trapped in the mineable oil sands region will be analyzed for PAHs, their alkyl congeners and heavy metals. The animals were obtained from local trappers in the winter of 2013/14. Tissues were dissected at the University of Alberta (Dr. Margo Pybus' wildlife pathology lab) and homogenized at Environment Canada's National Wildlife Research Center in Ottawa before submission to Alberta Innovates - Technology Futures (AITF – Vegreville) for analysis. AITF (Graham Knox, Brian Fahlman) and Environment Canada (Philippe Thomas) will produce a report on the contaminant burdens measured, as well as an analysis of whether it is feasible to pool samples (combine tissues from several individuals) or whether it is necessary to measure the contaminant burdens in separate individuals to effectively monitor these industrial pollutants in wildlife.

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4.2 Completed Projects

4.2.1 *An Evaluation of Wireless Sensor Networks and their Potential Implementation to Monitor Environmental Variables at Oil Sands Sites – Dr. Arturo Sanchez-Azofeifa, University of Alberta*

Report: Taheriazad, L., C. Portillo-Quintero and G.A. Sanchez-Azofeifa, 2014. Application of Wireless Sensor Networks (WSNs) to Oil Sands Environmental Monitoring. OSRIN Report No. TR-48. 51 pp. http://hdl.handle.net/10402/era.38858

Abstract: Monitoring of environmental conditions in and around oil sands developments has been underway for years. However, recent reviews have indicated the need for a more comprehensive, scientifically-rigourous and transparent monitoring program and have provided recommendations for design and oversight.

This report presents a comprehensive review of industrial applications of an emerging environmental monitoring technology called Wireless Sensor Networks (WSN). This technology consists of a series of individual wireless nodes that have the capacity to measure different micro-climatic as well as other chemical variables at costs that are significantly cheaper that current wired systems. This review describes monitoring in four main sectors: agricultural, environmental, forest, and industrial. The report reviews publications over the last 13-years; none of the case studies are from Alberta.

The report also provides a description of the establishment of a new Alberta project in which a WSN is used to monitor environmental conditions at a coal mine reclamation site. The WSN is installed at Coal Valley Mine (CVM, Central Alberta), and it represents a collaborative project between the Centre for Earth Observation Sciences (CEOS) at the University of Alberta, Alberta Environment and Sustainable Resource Development, and CVM. The system, logistical needs, and the data management system used to obtain, visualize and analyze the environmental data currently collected at CVM are described.

Given current environmental monitoring needs, plus the large areal extent of the oil sands region, wireless sensor networks have the potential to support traditional monitoring networks. The federal/provincial oil sands environmental monitoring implementation plan specifically mentions the use of remote sensing tools to enhance the monitoring system. More work is required to develop additional sensors specific to chemicals of concern in the oil sands and implement this technology in regional monitoring.

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4.2.2 *A Rapid Solution for Screening and Quantifying Targeted and Non-Targeted Analytes in Oil Sands Process Water and Natural Waters in the Athabasca Region – Dr. Jonathan Martin, University of Alberta*

Report: Pereira, A.S. and J.W. Martin, 2014. On-Line Solid Phase Extraction – HPLC – Orbitrap Mass Spectrometry for Screening and Quantifying Targeted and Non-Targeted Analytes in Oil Sands Process-Affected Water and Natural Waters in the Athabasca Oil Sands Region. OSRIN Report No. TR-45. 33 pp. http://hdl.handle.net/10402/era.37793

Abstract: In response to mounting evidence of local environmental contamination around the Alberta oil sands industry, the Alberta Environmental Monitoring Panel announced a new *world class environmental monitoring program* for the Alberta oil sands region in early 2011, and a new monitoring system is now being delivered jointly by the Government of Canada and the Government of Alberta. This new program involves much more frequent sampling of water at many locations around oil sands activity. However, a particular challenge remains that there are currently no proven or validated analytical methods for characterizing the highly complex mixture of organic compounds in bitumen-impacted waters which meet requirements for qualitative and quantitative accuracy, sensitivity, precision, and high throughput.

To address this need, an on-line solid phase extraction (SPE) technique was developed for oil sands process-affected water (OSPW), and for natural surface and groundwater samples in the Athabasca oil sands region. The on-line SPE method was connected directly to a high pressure liquid chromatography – Orbitrap mass spectrometry (SPE-HPLC-Orbitrap MS) instrumental system, allowing comprehensive profiling of thousands of dissolved organic compounds, and quantitative analysis of naphthenic acids (NAs), with only 5 mL of a natural water sample. The new method improves upon existing methods by reducing sample volume requirements, eliminating sample preparation time, reducing the possibility of contamination, and increasing the accuracy and precision without sacrificing chromatographic performance, method sensitivity, or method quantitative quality.

The new method is anticipated to be useful for high-throughput environmental water monitoring for purposes of current or future environmental compliance by industry, or for forensic source elucidation by monitoring programs and researchers. The method requires a small investment in equipment to setup, but can pay for itself in terms of cost (e.g., solvents and disposable SPEs), and time savings (cost of technician's time in manual solid phase extraction or other extraction step), not to mention the more precise and higher quality data that are resultant. Considering the capital cost of any HPLC-ultra-high resolution mass spectrometer system (e.g., minimum $600k), it is the opinion of the authors that the minor additional cost of on-line solid phase extraction can be well justified for Provincial and/or Federal water monitoring around oil sands development.

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4.2.3 *Assessment and Design of a Challenge Dialogue titled "What Constitutes Monitoring Adequacy in the Oil Sands Region?" – Doug James, Congruent Strategies*

In this first phase of the Monitoring Challenge Dialog project in 3.4.2 below, the consultants worked with a Committee to develop the scope for a Challenge Dialog and prepared a first draft of the Challenge Paper.

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4.2.4 *Assessment of Air Quality Remote Sensing Technology for Alberta's Oil Sands Region – Dr. Zaher Hashisho, University of Alberta*

Report: Marey, H.S., Z. Hashisho and L. Fu, 2014. Satellite Remote Sensing of Air Quality in the Oil Sands Region. OSRIN Report No. TR-49. 104 pp. http://hdl.handle.net/10402/era.38882

Abstract: The rapid expansion of oil sands activities and massive energy requirements to extract and upgrade the bitumen have led to a need for more comprehensive understanding of their potential environmental impacts, particularly on air quality. There are many oil sands developments and natural sources (point, area and mobile) that generate significant emissions, including nitrogen (NO_2) and sulphur oxides (SO_2), carbon monoxide (CO), and particulate matter. These chemicals are known to affect human health and climate. Thus an environmental monitoring program that measures the ambient air quality is needed to understand air pollutant emissions, their chemical transformation in the atmosphere, long-range transport and subsequent deposition to the local and regional environment.

Several studies have been conducted to understand the impact of the oil sands projects on the air quality over Alberta using ground-based measurements. However, data from these measurements are limited in spatial coverage as they reflect local air quality and cannot provide information about the overall regional air quality. A complementary approach to ground-based measurements is satellite-based monitoring which can provide large spatial and vertical coverage and allow monitoring of local and regional air quality. The objective of this report is to review available remote sensing technologies for monitoring and understanding the tropospheric constituents in the atmosphere, and potential use for monitoring the air quality over the oil sands region. The report includes a summary of the basic principles of remote sensing using satellites for tropospheric composition measurements; a detailed description of the instruments and techniques used for atmospheric remote sensing from space; demonstration of the key findings and results of using satellite data for air quality application; a brief summary of future missions; and, a case study to demonstrate the use of satellite data to study the impact of oil sands and other sources on carbon monoxide levels over Alberta.

The science of atmospheric remote sensing has dramatically evolved over the past two decades and proved to be capable of observing a wide range of chemical species (e.g., aerosols, tropospheric O_3, tropospheric NO_2, CO, HCHO, and SO_2) at increasingly higher spatial and temporal resolution. The integrated use of ground-based and satellite data for air quality applications has proven to be of enormous benefit to our understanding of the global distribution, sources, and trends of air pollutants. Despite the significance of using satellites in characterizations of air quality, there is limited research on using satellite-based remote sensing technology over Alberta. As satellite-based techniques now provide an essential component of observational strategies on regional and global scales, it is recommended to integrate data from satellite, and ground-based measurements as well as chemical transport models for air quality monitoring.

This report provides an in depth review of the developments in the atmospheric remote sensing area that may support air quality management, policy, and decision makers at the national, and regional level to take actions to control the exposure to air pollution.

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4.2.5 *Characterizing the Organic Composition of Snow and Surface Water Across the Athabasca Region – Phase 2 – Dr. Jean Birks, Alberta Innovates – Technology Futures*

Report: Birks, J., Y. Yi, S. Cho, E. Taylor and J. Gibson, 2014. Characterizing the Organic Composition of Snow and Surface Water Across the Athabasca Region: Phase 2. OSRIN Report No. TR-64. 47 pp. http://hdl.handle.net/10402/era.40243

Abstract: This study was conducted to characterize the composition of polar dissolved organic compounds present in snow and surface waters in the Athabasca Oil Sands Region (AOSR) with the goal of identifying whether atmospherically-derived organics present in snow are an important contributor to the dissolved organics detected in surface waters in the AOSR.

The Phase 1 OSRIN study (2013) was a pilot scale project conducted in 2011-2012 to evaluate whether Electrospray Ionization (ESI) coupled with Fourier Transform Ion Cyclotron Mass Spectrometry (FTICR MS) would be a useful analytical technique to characterize the dissolved organics in snow. Although a limited number of samples (i.e., 7 snow samples) were used in the Phase 1 study, the results indicated differences in organic signatures between the snow samples closest to oil sands activities and the more far-field samples.

The Phase 2 project includes a similar comparison of the composition of organics present in snow and surface water as was conducted in Phase 1, but is based on a more spatially and temporally comprehensive set of samples which allows a more extensive investigation of the spatial, temporal and species variations in snow and river water. Phase 2 also combines hydrometric data with the stable isotopic composition of snow and river water to identify when snowmelt appears in river discharge.

The dissolved organic composition results identified three snow groups. Group 1 snow tended to have O_2 as the dominant compound class, followed by O_4 compound classes. The snow samples from locations farthest from industrial activities had Group 1 organic profiles. The organic profiles for Group 2 had O_4 as the most abundant compound class and a pattern of decreasing relative contributions from the O_4 to O_{12} classes. There were only six Group 2 snow samples, but they were collected from either the geographical centre (GC) or near mining activities. The remaining snow samples that did not have similar dissolved organic compositions as Group 1 or Group 2 were categorized as Group 3 and were obtained from various locations.

The organic profiles obtained for the 110 river samples (84 tributary samples and 26 main stem Athabasca River samples) showed large differences between the composition of dissolved organics present in river water and those present in snow. River samples tended to have a greater relative contribution of O_6 to O_8 and S_2O_n (n = 4 to 9) compound classes than snow samples.

More subtle differences in organic profiles were also evident between the individual river samples related to sampling location and season. Comparing the organic profile results between the river and snow samples show the different types of relationships that exist between river and snow dissolved organic compositions. The monthly river samples collected from the main stem Athabasca River and from one tributary sampling location (i.e., Muskeg 8) tend to have organic compositions that become more similar to Group 1 snow samples over the open water season. The other tributary sampling locations tended to have dissolved organic compositions that become more similar to Group 2 or Group3 snow compositions over the open water season. The river samples differed from snow in that the dissolved organics present in river water are dominated by O_6 to O_8 classes in oxygen containing compounds, and contain a greater relative contribution S_2O_n (n = 4 to 9).

Also, the Athabasca River samples had slightly different organic compositions than the tributaries, with higher relative contributions of O_2 class compounds than in the tributaries. The main stem Athabasca River samples also contained some SO_3 compounds that were not detected in the tributary samples.

All of the river samples showed seasonal variations in dissolved organics, with larger variations in the Athabasca River than in tributaries. The distribution of compound classes in the river samples did not change significantly between May and September, but the dominance of O_2 classes becomes more pronounced in September, particularly in the Athabasca main stem sample.

The river discharge and stable water isotope data indicate that snowmelt was a major component of the May river samples, but the dissolved organics present in the May river samples did not resemble those present in snow. The months with the greatest similarity between snow and river organic compositions were low flow periods in March, April, and September, which could indicate significant delays between when atmospheric organics are released from the snowpack and when they reach the rivers, or that some of the organics present in snow are similar to organics that characterize baseflow.

In summary, the results of this comprehensive profiling of organics in snow and river water across the AOSR suggest that nitrogen and sulphur containing compounds may be the most useful in improving our understanding of the sources and fate of atmospherically derived organics in the oil sands region. There are still some endmembers that need improved organic characterization, including baseflow (groundwater inputs and soil water in disturbed and undisturbed watersheds) to the Athabasca River and its tributaries. Direct sampling of dissolved organics that can be attributed to natural and anthropogenic atmospheric sources of organics (e.g., forest fire, stack emissions, fugitive emissions) are also needed.

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4.2.6 *Dialogue on Monitoring and Information Reporting Adequacy – Doug James, Congruent Strategies*

Report: James, D.R. and T. Vold, 2010. Establishing a World Class Public Information and Reporting System for Ecosystems in the Oil Sands Region – Report and Appendices. OSRIN Report No. TR-5. 189 pp. http://hdl.handle.net/10402/era.19093

Also available in a shorter version without the detailed appendices – James, D.R. and T. Vold, 2010. Establishing a World Class Public Information and Reporting System for Ecosystems in the Oil Sands Region – Report. OSRIN Report No. TR-5A. 31 pp. http://hdl.handle.net/10402/era.19094

Abstract: This report presents a vision for a comprehensive and effective Public Information and Reporting System for Ecosystem Effects in the Oil Sands Region that is relevant, credible, durable, transparent, and robust. The report describes the key Principles and Elements of an information and reporting system that would provide Albertan's and the World with assurance that ecosystem effects due to development in the Wood Buffalo region are reported and evaluated and, along with socio-economic information, support decision-making and responsible management of the land, air and water. The report describes two Scenarios to improve the current system.

This report was developed through an intensive six month (January to June, 2010) structured process called the Challenge Dialogue System where we addressed the question of "What Constitutes an Adequate and Effective Public Information and Reporting System for Ecosystems in the Oil Sands Region?" This process involved 70 people drawn from industry, government (all levels), NGOs, First Nations, academia and the public. A one-day workshop in June 2010, attended by 25 people from government, industry, NGOs and staff from the four major monitoring programs in the Wood Buffalo Region, further refined the concepts arising from the written feedback.

The Principles for an effective information and reporting system are:

- Relevant (responsive, addresses key objectives, supports decisions)
- Credible (science-based, consistent methodology, standardized reporting, verifiable, independent and objective, collaborative)
- Understandable (increases public awareness, causal relations understood)
- Transparent (publicly available data, methodology and reports, timely reporting)
- Robust (durable, continuously-improving)

Two scenarios were developed to provide advice to improving the current information and report system for ecosystem effects in the oil sands region. These scenarios are:

- An Enhanced Information and Reporting System developed from the current assemblage of monitoring and reporting programs; and
- A World Class Information and Reporting System that incorporates or replaces the current system.

The Key Criteria for a World Class Information and Reporting System are:

- Independence

- Responsiveness
- Administrative and operational integration
- Transparent and collaborative governance structure
- Stable funding
- Integration across media
- Ease of access to data and information
- Excellence in reporting and communication
- Understanding of causal relationships
- Complex science-based information is understandable by all audiences
- Operational excellence
- Continuous improvement

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4.2.7 *Evaluation of Community Level Physiological Profiling as a Means of Assessing Aquatic Ecosystem Health in the Oil Sands Region – Jim Davies, Alberta Innovates – Technology Futures*

Report: Davies, J. and B. Eaton, 2011. Community Level Physiological Profiling for Monitoring Oil Sands Impacts. OSRIN Report No. TR-10. 44 pp. http://hdl.handle.net/10402/era.22781

Abstract: Alberta Innovates – Technology Futures (AITF) conducted a review of microbial Community Level Physiological Profiling (CLPP) as a means of monitoring aquatic ecosystem health for the Oil Sands Research and Information Network (OSRIN). Relevant research was compiled from journal articles, the websites of government and non-governmental organizations, and in-house experimental results. The objective of the project was to better understand and describe the potential for CLPP to provide meaningful assessments of aquatic ecosystems in the oil sands region of Alberta to various stakeholder groups.

Ecological monitoring techniques are used to assess the effects of industrial development in the region, and to assess the effectiveness of reclamation efforts. Current techniques, while effective, are difficult and expensive to implement on a regional scale. As a group, microbial community profiling technologies offer the potential to screen multiple systems rapidly, inexpensively, and relatively easily, compared to traditional assessment methods.

CLPP has the potential to be the easiest and least expensive microbial profiling technology. However, some technical advancements must still be made before its full potential can be realized. Beyond this, a significant body of background information regarding the effect of a number of environmental variables on the profiles produced by CLPP must be compiled, both as a source of reference information and to better define the performance characteristics of the assay.

A number of organizations conduct ecological research and/or monitoring in the region. Some (e.g., RAMP, AENV) could see direct benefits from the incorporation of CLPP into their operations. Others (e.g., CONRAD, CEMA) may realize a lesser degree of benefit.

Organizations focussing on specific aspects of aquatic ecosystems (e.g., DUC, DFO) are unlikely to see their missions advanced by the adoption of CLPP as an ecological monitoring tool.

Overall, AITF recommend investment of time and resources into CLPP and microbial community profiling in general. The expenditures required are likely to be quite small compared to the potential utility of the technology.

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4.2.8 *Instruments for Research on Air Quality Control and Characterization – Dr. Zaher Hashisho, University of Alberta*

Dr. Hashisho purchased equipment related to research into air emission control and characterization of tailings pond emissions, including a differential optical absorption spectroscopy air monitoring system, a gas chromatography-mass spectrometry with a canister concentrator system, and a microwave generation and monitoring system.

More specifically, the differential optical absorption spectroscopy air monitoring system will be used for remote monitoring of Volatile Organic Compounds (VOCs) and inorganic pollutants emitted from oil sand tailing ponds and other fugitive sources. The gas chromatography-mass spectrometer will be used for the characterization of VOC species in ambient air and the microwave generation and monitoring system is used for research on selective regeneration of adsorbents with microwave heating, and remediation of contaminated soil using microwave energy.

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4.2.9 *Inventory and Characterize the Monitoring and Reporting of Oil Sands Environmental Health – Eric Lott, EO Consulting*

Report: Lott, E.O. and R.K. Jones, 2010. Review of Four Major Environmental Effects Monitoring Programs in the Oil Sands Region. OSRIN Report No. TR-6. 114 pp. http://hdl.handle.net/10402/65.20287

Abstract: There is a general lack of awareness of existing environmental effects monitoring programs for the mineable oil sands region. As a result, there is low public confidence in the nature and extent of the current environment health monitoring and reporting programs for the oil sands with respect to potential impacts of these developments on environmental and human health. The purpose of this study was to engage four main environmental effects monitoring and reporting organizations currently operating in the oil sands area to document their programs. Through an engagement and validation process, program information was tagged, inventoried and characterized.

Each of these organizations is unique; they all play specialized roles in providing information, data and understanding of ecosystem effects. These organizations also provide vital monitoring information based on their media, or domain expertise that is essential to understanding the ecosystem health and human health of the oil sands area.

The resultant information was captured and presented in the form of a one-page visual Summary of Environmental Effects Monitoring in the Oil Sands Area. Additional contextual information adds to the understanding of the current state and is presented as a Chronology of Environmental Effects Monitoring Activities (1990-2010). Detailed Fact Sheets are provided for each of the four monitoring programs:

- Alberta Biodiversity Monitoring Institute (ABMI)
- Cumulative Environmental Management Association (CEMA)
- Regional Aquatic Monitoring Program (RAMP)
- Wood Buffalo Environmental Association (WBEA)

The report concludes by making some observations of the programs studied. The recommendations presented represent possible next steps to build on this body of work. The central observation and recommendation is that stakeholders, including the monitoring program staff themselves, lack a detailed understanding of the full suite of monitoring activities taking place in the oil sands area and in moving forward, a more integrated approach would benefit both the existing environmental effects monitoring programs and the ability to speak authoritatively about oil sands ecosystem effects as a whole.

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4.2.10 *Isotope and Geochemical Tracers for Fingerprinting Process-Affected Waters in the Oil Sands Industry – Dr. John Gibson, Alberta Innovates – Technology Futures*

Report: Gibson, J.J., S.J. Birks, M. Moncur, Y. Yi, K. Tattrie, S. Jasechko, K. Richardson, and P. Eby, 2011. Isotopic and Geochemical Tracers for Fingerprinting Process-Affected Waters in the Oil Sands Industry: A Pilot Study. OSRIN Report No. TR-12. 109 pp. http://hdl.handle.net/10402/era.23000

Abstract: A pilot study was conducted by Alberta Innovates – Technology Futures during 2009 and 2010 to assess potential for labelling process-affected water from oil sands operations using a suite of isotopic and geochemical tracers, including inorganic and organic compounds in water. The study was initiated in response to a request from Alberta Environment and grant funds for the project were obtained from the Oil Sands Research and Information Network, University of Alberta. Three oil sands operators participated in the study, providing logistical support and/or personnel to assist with on-lease water sampling. Alberta Environment and its consultants also provided support for sampling of groundwater. At the outset of the study, Worley Parsons was subcontracted to carry out a detailed electromagnetic survey of the Athabasca River from Fort McMurray to the confluence of the Firebag River, to map high conductivity seeps as potential targets for water sampling. While the priority of this first phase of the study was fingerprinting of water sources (i.e., tailings ponds vs. natural groundwater, lakes, and river water), the survey also sampled a selection of river bed seeps to test application of the methods to identify the origin of these waters near the point of discharge to the Athabasca River.

In total 39 samples were collected for this study. These included 8 process-affected water samples, 6 groundwater samples, 8 river bed seepage samples, and 15 river samples. A variety

of isotope tracers were measured including oxygen-18 ($\delta^{18}O_{H2O}$) and deuterium ($\delta^{2}H_{H2O}$) in water, enriched tritium ($e^{3}H$) in water, carbon-13 in dissolved organic carbon ($\delta^{13}C_{DOC}$), carbon-13 and carbon-14 in dissolved inorganic carbon ($\delta^{13}C_{DIC}$, ^{14}C), sulfur-34 in dissolved sulfate ($\delta^{34}S_{SO4}$), chlorine-37 in dissolved chloride ($\delta^{37}Cl$), and strontium-87 versus strontium-86 ($^{87}Sr/^{86}Sr$) and boron-11 ($\delta^{11}B$) in dissolved solids. Geochemical analyses included major-, minor- and trace elements, a range of metals, nutrients and total organic carbon, as well as 113 priority pollutants and naphthenic acids. Fourier transform ion cyclotron resonance mass spectrometry (FT-ICR MS) was also used to scan for thousands of organic compounds in the water samples.

Overall, while selected isotopic and geochemical tracers were found to be definitive for labelling water sources in some locations, it is unreliable to attempt any universal labelling of water sources based solely on individual tracers or simple combinations of tracers. Understanding of the regional hydrogeological system, and interpretation of tracer variations in the context of a biogeochemical systems approach on a case by case basis offers the greatest potential for comprehensive understanding and labelling of water source and pathways. While limited in number of samples, the survey demonstrates the complimentary use of various fingerprinting techniques.

Preliminary evaluation of statistical approaches for differentiating various water types using inorganic, organic and combined datasets yielded promising results. These methods potentially offer multiple lines of evidence for fingerprinting and should be further evaluated, refined and applied as part of more comprehensive future investigations.

While organic and inorganic tracers were capable of fingerprinting process-affected water sources from different operators, identification of seep sources along the Athabasca River was much more challenging due to presence of complex water mixtures including groundwater and significant river water. The presence or absence of process-affected water in seeps along developed portions of the river remains to be verified and will require further baseline surveys.

FT-ICR MS offers capability to resolve thousands of organic compounds, and may be the simplest, most cost-effective approach to build a baseline dataset for use in identification of process-affected waters in the natural aquatic environment. A wide range of organic compounds are observed in process-affected water and these are not limited to naphthenic acids and hydrocarbons.

Further work to constrain sources, pathways and receptors of process-affected water needs to be undertaken. From a riverine perspective, synoptic surveys offer an integrative method for better understanding of evolution of the Athabasca River and tributaries as it may be affected by addition of both natural and potentially process-affected water.

We find no evidence of robust connections between tailings ponds and the river seeps that were sampled over the 125-km reach traversing the oil sands development area, although many seeps were not sampled. Although the seeps we did sample appear to be directly related to occurrence of natural groundwater seepage, we do not have enough evidence at this point to rule out the possibility that minor or trace amounts of process-affected water may be present in some of these seeps.

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4.2.11 *Metrics for Assessing Fisheries Productivity of Oil Sands Compensation Lakes – Dr. Mark Poesch, University of Alberta*

Report: Christensen-Dalsgaard, K.K., R.N. Sinnatamby and M. Poesch, 2014. Metrics for Assessing Fisheries Productivity and Offsetting Strategies under Canada's New *Fisheries Act*. OSRIN Report No. TR-70. 58 pp. http://hdl.handle.net/10402/era.40345

Abstract: The Alberta oil sands region contains one of the world's largest oil deposits, estimated at 1.7 trillion barrels. Development in this region can have negative effects for aquatic species, governed under Canada's *Fisheries Act*. The *Fisheries Act* allows the possibility for offsetting losses in fisheries productivity, e.g., through the creation of compensation lakes. Offsetting strategies are becoming increasingly important for large-scale developments such as mining operations in the oil sands region; they allow for development while ensuring that the project has 'no net loss' in fisheries productivity.

In 2012, omnibus Bill C-38 fundamentally changed large sections of the federal *Fisheries Act*. The focus of fisheries management was shifted from the protection of fish habitat in general to ensuring the ongoing productivity (FP) of fish important to commercial, recreational and aboriginal (CRA) fisheries. Further, the changes formalized the use of offsetting strategies to compensate for damage to fish caused by development.

The changes marked the move from the fisheries habitat management program (FHMP) as implemented prior to 2012, to the fisheries protection program (FPP). The goal of the FPP is to "provide for the sustainability and ongoing productivity of commercial, recreational and Aboriginal fisheries". Lack of standardized protocols and procedures following a shift of this magnitude could not only result in considerable additional expenses for industry, but also in less reproducible and so less reliable results. Rapid standardization of best practices and data collection methods would help ensure cost-efficient, meaningful and transferable data. Currently, these best management practices are being determined through an ongoing process involving Fisheries and Oceans Canada (DFO), industrial partners and government officials. The aim is to define a standard set of indicators for use under the FPP framework and assess which models may suitable for forming the link between data sets and long-term projections for whole-population productivity.

The interpretation of the changes to the *Fisheries Act* has been subject to controversy, making concise and publically available information important. Numerous scientific advisory reports have been published by DFO. However, there is currently a shortage of documents that give an overview over the scientific background necessary to understand how the changes may affect management practices, taking into account knowledge gaps and limitations in terms of data collection techniques. In this report, we will review existing monitoring tools as well as how the

changes in policies associated with the shift from the FHMP to the FPP may affect management protocols.

Under the FHMP, the conceptual endpoint for assessing the impacts of development on fisheries was to achieve no net loss of the productive capacity of fish habitat (PC). Habitat was quantified mainly by area, and the success of an offsetting project was often determined mainly through acceptable installation. Methods in use under the FHMP provided only approximate values for PC.

For a meaningful planning, measurement and monitoring protocol that can help ensure fisheries productivity under the FPP, it may be necessary to move away from the previous practice of managing fish habitat in Canada based on the use of FP as a theoretical concept only. As productivity in itself is difficult to measure directly, it is necessary to find appropriate indicators that can link changes in the components of productivity of individual fish or subsections of populations to changes in population-level fisheries productivity. We have compiled a list of indicators that may be used for estimating productivity of fisheries populations.

Solid measurements of fisheries productivity require repeated monitoring protocols extended over multiple years as well as a broadening of the definition of habitat affected by development. The financially and ecologically prohibitive nature of obtaining comprehensive, long-term data sets may make models an essential tool for linking limited data on subsets of populations with whole-population productivity and long-term projections. However, the trade-off between strength of model predictions and quality and quantity of data may make it a challenge to strike the balance between data needs for accurate predictions and financial feasibility.

In using knowledge-based standards for planning and executing compensation lake development, a key parameter to evaluate would be the carrying capacity of various compensation lake ecosystems. It may be a challenge to ensure an appropriate agreement between offsetting indicators and environmental assessment indicators, as established ecosystems are compared with populations in the process of establishing in a newly expanded habitat. On the other hand, lack of density dependence in the early establishment phase gives good possibilities for providing solid estimates of intrinsic growth rate of the populations within this specific habitat.

Future research should be conducted for areas characterized by intensive development to create models that allow for robust estimates of productivity based on limited and specific indicators that are manageable to measure. As factors limiting fisheries productivity vary between species, habitats and regions, it is likely that this would have to occur through the development of models specific for the given habitats and geographical areas.

If the drivers of the ecosystem in question are not well studied, the most cost-effective and ecologically sound way of implementing the FPP may be to adopt the management practices of the FHMP largely unaltered, but with the interpretive end goal shifted to FP. This would only require a mandatory inclusion of population level data in the monitoring protocols, and an extended monitoring period of several years. All of this constitutes protocols already in use under the FHMP. Though much work has been done on measuring and modelling the productivity of fish populations, it has proven difficult or impossible to find simple, reproducible techniques that can be applied across habitat types and ecosystems. In our opinion, the best predictors for fisheries productivity remain the quantity and quality of available fish habitat combined with abundance, size structure data and species composition within the given habitats.

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4.2.12 *Microcosm Evaluation of CLPP in Oil Sands Process Affected Water – Dr. Jim Davies, Alberta Innovates – Technology Futures*

Report: Davies, J., B. Eaton and D. Humphries, 2012. Microcosm Evaluation of Community Level Physiological Profiling in Oil Sands Process Affected Water. OSRIN Report No. TR-28. 33 pp. http://hdl.handle.net/10402/era.29322

Abstract: A microcosm-based experiment was conducted to investigate the ability of community level physiological profiling (CLPP) to detect changes in an aquatic microbial community resulting from exposure to oil sands process affected water (OSPW). Detection of the microbial response was done by using the Biolog EcoPlate system, a commercially-available system originally developed for the assessment of rhizosphere microbial communities. The Biolog system consists of a 96-well microtitre plate. Each well on the plate contains both a pure organic compound (the substrate), and a tetrazolium dye. When a microorganism metabolizes the substrate, the dye is reduced into a purple formazan product. The purple colour of each well is characterized using a spectrophotometer measuring optical density (OD) at 590 nm. In this study, we used the EcoPlate version of the Biolog System.

Reductions in metabolic activity and inoculum density were detected in the high OSPW group. Overall, indicators of microbial metabolic activity decreased over time. One of these indicators, the sum of substrate means (SSM), showed a dramatic response to weekly water changes. Low cyclicity naphthenic acids demonstrated a reduction over the first and last weeks of the exposure period. Higher cyclicity naphthenic acids demonstrated reductions in the first but not the last week of exposure. The total naphthenic acid (TNA) content of the microcosms appeared to increase over the last week of the exposure period, which may reflect the accumulation of products of microbial metabolism.

Our results suggest that inoculum density remains a source of variability for CLPP results. Furthermore, the biological context under which the microbial community forms has a strong influence on its metabolic characteristics. The changes in naphthenic acid concentration (total and speciated) likely reflect adsorption and/or microbial metabolism. Our observation of increased phytoplankton in the presence of OSPW is consistent with the available literature. Additional research will be required to determine if this finding can be developed into an indicator of toxic effect, rather than just the presence/concentration of OSPW.

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4.2.13 *Modeling and Assessing the Impact of Oil Sands Contaminants on Aquatic Food Webs – Dr. Mark Lewis, University of Alberta*

Report: Huang, Q., H. Wang and M.A. Lewis, 2014. Development of a Toxin-Mediated Predator-Prey Model Applicable to Aquatic Environments in the Athabasca Oil Sands Region. OSRIN Report No. TR-59. 59 pp. http://hdl.handle.net/10402/era.40140

Abstract: Industrial contaminants are one of the leading causes of pollution worldwide. It has been shown that 13 elements considered priority water pollutants by the US Environmental Protection Agency are present in the Athabasca River and are found in oil sands process-affected water. There are likely natural and anthropogenic sources of these toxins in the receiving environment. To protect ecological environments and aquatic species in Alberta, it is necessary to assess the risk of toxins to aquatic organisms, and find important factors that determine the persistence and extirpation of populations or species.

While previous work has considered the effect of a toxin on the population dynamics of a single trophic level, such as fish, we focus on the impacts of toxins on the population dynamics of aquatic food webs to understand possible outcomes.

Mathematical models have been widely applied to perform chemical risk assessments on all levels of the biological hierarchy, from cells to organs to organisms to populations to entire ecosystems. Here we develop a toxin-mediated predator-prey model that includes population dynamics. We use the model to evaluate the flow of toxins through the aquatic food web into the aquatic ecosystem and study how the transfer of toxins between trophic levels changes the food web dynamics. We analyze the model by studying the existence and stability of steady states and the effect of toxin level in the environment on steady states.

The model is then connected to experimental data via model parameterization. In particular, we consider the toxic effects of methylmercury on rainbow trout (*Oncorhynchus mykiss*) and its prey (small fish or aquatic insects) and obtain an appropriate estimate for each model parameter. The results of model parameterization and model analysis are used to numerically solve the model, and the results of the effect of the methylmercury on the end behavior of rainbow trout and its prey (small fish or aquatic insects) are provided.

From our analysis and numerical exploration of the food web toxin model we found that different toxin concentrations affect organisms at different trophic levels in many different ways. For example, high toxin concentrations in the environment are harmful to both species, and may lead to extirpation of both species. However, low toxin concentrations produce counterintuitive results. That is, contaminant effects on predators can actually lead to increased abundance of the prey.

The existence of limit cycles, where both population levels fluctuate around coexistence equilibrium, is found in most classical predator-prey models. Our findings show that increasing toxin level may reduce and prevent populations from fluctuating when the predator and the prey are exposed simultaneously to a toxin. Unlike most standard predator-prey systems, where populations will eventually tend toward only one stable state, our findings indicate that with a

toxic effect, predator-prey systems may lead to multiple possible long-term outcomes. In this scenario, the initial population level will determine the final fate.

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4.2.14 *Oil Sands Groundwater – Surface Water Interactions Workshop – Oil Sands Research and Information Network and Canadian Environmental Assessment Agency*

Report: Oil Sands Research and Information Network and Canadian Environmental Assessment Agency, 2012. Summary of the Oil Sands Groundwater – Surface Water Interactions Workshop. OSRIN Report No. TR-22. 125 pp. http://hdl.handle.net/10402/era.26831

Abstract: A number of factors led to the need for a workshop to discuss surface water – groundwater interactions in the oil sands. These included:

- Current government policies and the development of new policies and frameworks
- Continued uncertainty regarding the potential for interactions and the resulting impacts, particularly for fisheries habitat and resources
- Initiation of the Cumulative Environmental Management Association's Groundwater Working Group and their initial research results
- Work being undertaken by industry, particularly in the Southern Athabasca Oil Sands

The Workshop:

- Considered mineable and in-situ oil sands operations in general (i.e., did not focus on specific geographic regions, except when discussing specific examples)
- Focused mainly on groundwater (quality and quantity) – with discussion of surface water being limited to "groundwater – surface water interaction"
- Acknowledged, but did not address, that the different regulators have different responsibilities and authorities regarding groundwater, surface water and fisheries impacts related to interactions

The objectives of the Workshop were to:

- Develop a common understanding of the current knowledge regarding groundwater resources, groundwater-surface water interactions in the oil sands area, ongoing applied research, monitoring and potential impacts
- Develop recommendations regarding research, monitoring, modelling, etc. to address knowledge gaps and/or regulatory and environmental protection issues

The Workshop was structured with initial presentations by several speakers to set the context, and summarize current policy and recent research. The participants were then asked to respond to a series of general and topic-specific questions.

The report recommendations have not been directed to any specific individual or organization. Rather, the Steering Committee members will bring the recommendations back to their respective management teams for further consideration.

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4.2.15 *Organic Footprint of Atmospheric Deposits: Snow and Surface Water Fingerprinting Across the Athabasca Region – Dr. Jean Birks, Alberta Innovates – Technology Futures*

Report: Birks, S.J., Y. Yi, S. Cho, J.J. Gibson and R. Hazewinkel, 2013. Characterizing the Organic Composition of Snow and Surface Water in the Athabasca Region. OSRIN Report No. TR-40. 62 pp. http://hdl.handle.net/10402/era.36643

Abstract: This pilot study was conducted by Alberta Innovates – Technology Futures (AITF) to characterize the composition of organics present in snow and surface waters in the Athabasca Oil Sands Region (AOSR) with the goal of identifying whether atmospherically-derived organics present in snow are a significant contributor to the organics detected in rivers and lakes in the region. This study is divided into two parts, each describing a different approach to characterizing the organics present in snow and surface waters. In Part 1, we interpret existing polycyclic aromatic hydrocarbon (PAH) concentration data, collected from various monitoring programs in 2011, to compare the composition of PAHs in snow and surface waters across the AOSR. In Part 2, we interpret new ultra-high resolution mass spectrometry analyses of snow and surface water samples collected in 2012 to compare the dissolved polar organics present in snow and surface waters in the Athabasca Oil Sands region (AOSR).

The first approach applied in this study uses existing data from snow, river and lake monitoring programs conducted during 2011 which measured total (dissolved + particulate) PAH concentrations in snow and surface waters in the region. The 2011 dataset includes total (dissolved + particulate) concentrations for 34 parent and alkylated PAH species for 105 snow, 272 Athabasca River and tributary, and 3 lake samples. These data were compiled so that the composition of PAHs in the Athabasca River, its tributaries and a small number of lakes could be compared with that of snowmelt. The snow data show compositional differences between the PAHs present in snow sampled from areas closest to oil sands activities (i.e., near-field sites) and from more distant (i.e., far-field) snow sampling locations. Despite large concentration variations in snow along geographic gradients, the composition of PAHs are found to be similar among near-field sites, but change significantly at far-field sites. Both the near- and far-field snow samples have PAH compositions that are different from the PAHs present in the Athabasca River, its tributaries and lakes. Compositional differences in PAH assemblages are also evident between tributaries and the Athabasca River. PAH concentrations in rivers are found to vary seasonally, with peak concentrations observed in July 2011 when Athabasca River levels were at their highest. However, the composition of PAHs present in July 2011 do not resemble the composition of PAHs identified in snow, suggesting that direct transfer of PAHs accumulated on snow from atmospheric deposition to Athabasca River and its tributaries in the area is not a

major source of PAHs present in surface waters. The timing of peak PAH concentrations in rivers, which coincides with a high flow period during freshet, does suggest that snowmelt may contribute indirectly to increases in PAH concentrations due to processes such as increased catchment runoff, erosion of stream channels, and snowmelt-induced groundwater inputs during this dynamic hydrologic period.

The second approach applied in this study uses Electrospray Ionization Fourier Transform Mass Spectrometry (ESI-FTICR MS) to characterize the dissolved polar organic composition of snow and surface water samples provided by various Alberta Environment and Sustainable Resource Development (AESRD) programs conducted in 2012. The 2012 samples analyzed by ESI-FTICR MS include 7 snow samples, 73 Athabasca River and tributary samples, and 6 lake samples. This profiling method identified thousands of dissolved polar compounds including the acidic organic components in negatively charged ESI(-) mode, and basic components in positively-charged ESI(+) mode. Although based on a limited number of samples, the organic profiles obtained for the snow samples in ESI(-) mode show compositional differences in the dissolved organics present in snow sampled from sites closest to oil sands activities (<5 km) and those sampled from more distant locations. There are also very significant compositional differences between the dissolved polar organics present in snow and surface waters in the AOSR. The composition of dissolved organics present in the Athabasca River upstream of the AOSR (i.e., Athabasca River at Athabasca) are found to be different from samples obtained from downstream sites in the vicinity of AOSR (i.e., Athabasca River at Fort McMurray and Athabasca River at Firebag confluence). The upstream Athabasca River sites tend to share some compositional similarities with far-field snow deposition, while the downstream Athabasca River sites are more similar to local tributaries. This contrast likely indicates shifts in the relative importance of regional snowmelt versus local inputs from small tributaries.

The results of these two separate approaches, which characterized different components of the organics present in snow and surface waters in the AOSR, leads to some similar conclusions. Both show compositional differences between the organics present in the snowpack near the centre of oil sands activities compared with more far-field locations and between the Athabasca River and its tributaries. The compositional differences between organics present in snow and those sampled in surface waters in the region suggest that even though the spring freshet is a period when elevated PAHs have been found in the Athabasca River the organics released directly from snow are not the dominant inputs during this peak discharge. These compositional differences may be useful tools for differentiating air-borne vs. water-borne organics away from the AOSR. The two methods used show the usefulness of PAH composition (i.e., relative concentrations of PAHs) and polar organic profiling in differentiating sources of organics in the region. The role of potential transformations of PAH and ESI-FTICR MS composition profiles during spring melt and during interactions along typical surface and subsurface flowpaths within wetland-dominated catchment areas typical of the region remains to be better understood.

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4.2.16 *Potential to Use Wildlife as Monitors of Ecosystem Health and Sustainability in the Oil Sands Region – Dr. Judit Smits, University of Calgary*

Report: Cruz-Martinez, L. and J.E.G. Smits, 2012. Potential to Use Animals as Monitors of Ecosystem Health in the Oil Sands Region – July 2013 Update. OSRIN Report No. TR-18. 52 pp. http://hdl.handle.net/10402/era.25417

Abstract: This review is focused on the effects of contaminants on wildlife and the potential for using wildlife as sentinels for human and environmental health. Some wildlife are permanent residents of the boreal forest encompassing the oil sands region, while many others are seasonal residents using this area as breeding grounds (i.e., migratory birds), both providing the potential for ongoing research into the biological effects of contaminants from oil sands activities.

Wildlife species may act as sentinels, or early warning systems, providing insight into the effects of contaminants on environmental and even human health. In the oil sands, both field and laboratory studies have used wildlife as bioindicators and/or sentinels of ecosystem health. The great majority of this research has focused on aquatic ecosystems and organisms.

Fish exposed to oil sands process affected water (OSPW), or water plus sediments from tailings ponds, and water from wetlands receiving oil sands effluents, have shown a range of detrimental physiological effects including increased detoxification activity by the liver, alterations in growth, hormonal disruption, abnormalities in hematological variables, pathologic changes in the gills, and increased mortality rates relative to fish from reference sites. Studies indicate that mature, reclaimed wetlands in the oil sands, those seven years or older, can support viable populations of locally important amphibians, whereas the younger wetlands retain toxic compounds which cause detrimental health effects such as decreased survival, delayed development, and increased rates of malformation.

Most research on birds has also focused on aquatic toxicology. Growth alterations (smaller skeletal size and body mass) have been reported in waterfowl raised on wetlands receiving oil sands effluent. Migrating waterfowl are at risk of landing on tailings ponds with floating bitumen, despite considerable efforts to design and deploy deterrent systems, and mass mortalities have resulted. Increased levels of mercury (Hg) in the eggs of water birds, and a positive correlation between Hg and naphthenic acid (NA) concentrations, suggests a common source of exposure for birds nesting on lakes that receive water from the Athabasca River downstream from the oil sands region. On the mine lease areas, reclaimed wetlands have in most years supported active populations of tree swallows during the breeding period and rearing of the offspring. However, stochastic events such as many days of cold, wet weather can cause severe stress resulting in high mortality rates. Studies of risk to mammals from tailings pond water suggest that terrestrial wildlife is unlikely to develop acute toxicity from NA exposure, although negative health effects may occur from repeated, or long-term exposures.

We have identified a conspicuous gap in knowledge related to effects of airborne contaminants on any species. Birds may prove especially valuable as sentinels because of the unique anatomy and physiology of their respiratory system (birds are more sensitive to airborne contaminants

than mammals of similar size). As well, as pointed out in the report from the Royal Society of Canada, "quantifying these emissions is notoriously difficult and the data available in the National Pollutant Release Inventory on this subject do not provide enough detail to know what sources have been estimated nor how valid the numbers are"; and, "the subject of non-point (fugitive) emissions of air contaminants from mines and tailings ponds is highly uncertain and currently available estimates are unlikely to be entirely valid".

One approach to better understand the effects of emissions on wildlife (and warm-blooded animals in general) could be through research on birds of prey (raptors). Raptors such as the American kestrel (*Falco sparverius*) could provide integrated insight into food web, as well as air borne exposure to environmental contaminants over time. Together with concurrent studies of their prey species, such as small mammals inhabiting reclaimed terrestrial areas, this type of work has the possibility of generating information relevant to the health of a range of animals in that ecosystem. Other studies of wildlife sentinels of ecosystem health could be based on herbivores. Domestic sheep and goats could serve as surrogates for caribou, moose and other ungulates naturally found in this region, for assessing health effects from deposition and accumulation of particulate air contaminants on vegetation. A final option would be to use small mammals such as mice and voles as sentinels of ecosystem health. Such species reflect the quality and quantity of local vegetation, readily populate any available area and serve as food for mammalian and avian predators.

For the oil sands as well as other petroleum producing regions, major emissions of interest are volatile organic compounds, hydrogen sulfide, sulphur dioxide, nitrogen dioxide, ozone and particulate matter, whereas aquatic contaminants related to the petrochemical industry are polycyclic aromatic hydrocarbons, naphthenic acids, sulphate ions, ammonia and trace metals. Once in the environment, complex interactions among contaminants and substrates along with inherent chemical characteristics will determine the fate of these compounds.

Extraction and production of bitumen from the oil sands produces compounds of environmental concern in the form of emissions perceived to pose risks to flora and fauna in local and downwind regions, and in the form of great volumes of liquid tailings. Research on wildlife species, used as either monitors, or indicator species, can provide early warning and predictive information regarding exposure and effects of contaminants from oil sands activities that would complement the huge ongoing investment into air and water monitoring systems.

Appendix 2 (added in Jul 2013) provides a summary of findings from a 2012 study of tree swallows with a focus on air-borne compounds, using these insectivores as sentinels, as described above.

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4.2.17 *Surface Water – Groundwater Interactions in the Lower Athabasca Region – Melanie Dubois, Cumulative Environmental Management Association*

Report: Birks, J., J.P. Jones and J. Gibson, 2012. Surface water - groundwater interactions in the lower Athabasca region. Cumulative Environmental Management Association, Fort

McMurray, Alberta. CEMA Contract No. GWWG 2011-0042. 75 pp. [Available from the CEMA website at http://library.cemaonline.ca/ – you must register to download the report].

Abstract: Recently, there has been an increased interest in further characterizing groundwater systems for a number of upcoming Oil Sands projects in the Lower Athabasca Region. Concomitant to this increased interest is a rising appreciation for the potential influence groundwater may have on surface water systems and vice versa. To date, the majority of the surface water – groundwater interaction work performed in the Lower Athabasca Region has focused on local scale processes with limited efforts at the regional scale. However, it is generally recognized that effective planning and management of the region's water resources will require a better understanding of these interactions at all scales.

The primary objective of this document is to present an outline of the initial steps and tools that will be necessary to achieve that better understanding. Section 1 discusses the current level of knowledge regarding surface water – groundwater interaction in the Lower Athabasca Region, identifies some of the anthropogenic processes that could be influencing them and outlines current and proposed monitoring frameworks relevant to those interactions. Section 2 presents an overview of the current spectrum of tools and techniques used to measure surface water – groundwater interaction in the Lower Athabasca Region and other jurisdictions. Section 3 summarizes some projects currently being conducted by government, industry and academics that are relevant to this topic. Section 4 presents a scope of work outlining the research that will be required in the short, medium, and long-term to improve our understanding of these interactions across the region. As well, a large bibliography of pertinent literature and reports is included in Appendix 1 for those wishing to explore some of the information discussed in this document further. Overall, it is hoped that the information and work scope presented in this document will help advance the ability to identify and quantify the cumulative effects of development in the region.

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4.2.18 *Wild Plant and Soil Sampling in Support of Oil Sands Contaminant Load Assessment – Dr. Cindy Jardine, University of Alberta*

Report: Hopkins, D, K. Wall and C. Wilson, 2014. Measured Concentrations of Metals and Polycyclic Aromatic Hydrocarbons in Plants, Berries and Soil Located North of Fort McMurray, Alberta. OSRIN Report No. TR-68. 134 pp. http://hdl.handle.net/10402/era.40339

Abstract: The objective of this study is to measure and characterize concentrations of chemicals in plants, berries and soil predominantly located north of Fort McMurray, Alberta. Methods included opportunistic sampling via collection of root vegetables, above ground vegetables, berries and soil and corresponding laboratory analysis to determine the concentrations of metals and polycyclic aromatic hydrocarbons (PAHs) in each environmental media. As well, the methods utilized for laboratory analysis, quality assurance and quality control are discussed. The results of the laboratory analysis for the chemical concentrations in each of the environmental media samples collected are presented.

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5 INCREASING AWARENESS

This program aims to increase awareness of OSRIN and oil sands issues through an active website presence (www.osrin.ualberta.ca), sponsoring oil sands related conferences, digitizing historical information and publication of OSRIN research results.

OSRIN reports are available on the University of Alberta's Education & Research Archive. The Technical Report (TR) series documents results of OSRIN funded projects. The Staff Reports (SR) series represent work done by OSRIN staff. OSRIN also has funded a video (V) related to one of its research projects. A full listing of the reports and video is available at the end of this report.

Project	Researcher
Completed Projects	
Background Information Journalists Need for Oil Sands Articles	Janice Paskey, Mount Royal University
CEMA Oil Sands Bibliography Enhancements	Kyle Harrietha, Cumulative Environmental Management Association
Develop Website Structure	James Murgatroyd Communications
Digitizing Historical Oil Sands Research Reports	OSRIN staff
iGEM Competition Sponsorship	Bob Mitchell, ConocoPhillips Canada
iGEM Oil Sands Awareness Project	OSRIN in partnership with the Oil Sands Leadership Initiative (OSLI)
Innovation Asset Database	UofA MBA Students
Investigating a Knowledge Exchange Network for the Reclamation Community	Alberta Innovates - Technology Futures
Media Monitoring Project	Troy Media Corp.
Oil Sands Rules, Tools and Capacity: Are we Ready for Upcoming Challenges?	OSRIN
Support to Innovation Asset Database Project	Stephen Murgatroyd, Murgatroyd Inc. Communications and Consulting
University of Alberta iGEM Team Sponsorship	Dr. Mike Ellison, University of Alberta

Project	Researcher
Web Portal Design	Stephen Murgatroyd, Murgatroyd Inc. Communications and Consulting

In addition to funding research projects, OSRIN sponsors a variety of conferences with oil sands themes as a means of increasing awareness of oil sands issues and of making people aware of OSRIN's work. Current and past sponsorships include:

- ISMOS 3 – 2011 Conference – June 2011
- IASTED ENV 2011 Conference – July 2011
- Mine Closure 2011 Conference – Sept 2011
- CPANS Fall 2011 Technical Conference – Nov 2011
- 2012 CONRAD Water Conference – March 2012
- University of Alberta Oil Sands Student Delegation Trip – Oct 2012
- RemTech 2012 – Oct 2012
- IOSTC 2012 – Dec 2012
- CONRAD 3rd Oil Sands Clay Conference and Workshop Feb 2013
- WaterTech 2013 Conference – Apr 2013
- University of Alberta Oil Sands Student Delegation 2013 Trip – Oct 2013
- Tailings and Mine Waste 2013 Conference – Nov 2013
- COSIA Oil Sands Water Conference and Workshops 2014 – March 2014
- University of Alberta Oil Sands Student Delegation 2013 Trip – Oct 2014
- IOSTC 2014 – Dec 2014
- COSIA Oil Sands Clay Conference and Workshop – April 2015
- WaterTech 2015 – April 2015
- RemTech 2015 – October 2015

5.1 Completed Projects

5.1.1 *Background Information Journalists Need for Oil Sands Articles – Janice Paskey, Mount Royal University*

Report: Paskey, J. and G. Steward, 2012. The Alberta Oil Sands, Journalists, and Their Sources. OSRIN Report No. TR-17. 33 pp. http://hdl.handle.net/10402/era.25266

Abstract: Twenty journalists who regularly produce articles, televised reports and videos about the Alberta oil sands and issues pertaining to the oil sands participated in this study.

Although most of the stories about the Alberta oil sands that appear in the news media have a business or economic focus, this study reveals that a clear majority of the 20 journalists who participated believe that the tension between economic and environmental aspects of oil sands development is the driving issue.

A clear majority of respondents also said that there are many stories about the oil sands that go unreported and many of these unreported stories have to do with environmental issues.

While journalists didn't specify why certain stories are not covered by the news media, they did report that some of the sources they would need to produce credible articles or documentaries are not easily available and, in some cases, not available at all. Most reported that industry sources are easily available although they would prefer to speak with decision makers rather than communications staff. And while they often rely on government statistics about the oil sands and the environment, a significant number of respondents said it is usually difficult to reach federal and provincial government representatives to discuss these statistics.

Academics have become an important source of expertise, particularly for journalists who write about environmental issues, as have advocacy groups such as the Pembina Institute. However, most journalists suggested that there are so many vested interests with a stake in oil sands development that it is often difficult to know who to believe. For this reason they use a variety of sources, especially when covering environmental issues.

Most journalists suggested that up-to-date expertise is such a valuable commodity when reporting about the oil sands that they expect all their sources to have it, even citizen and Aboriginal sources.

It is also apparent that most of the journalists rely heavily on online sources of information such as other media stories, government reports and documents, industry updates, advocacy group reports and events, contact information for Aboriginal bands, statistical information of all sorts, and media releases.

Most of the respondents were experienced journalists who have been covering the Alberta oil sands for more than five years. They believe that oil sands development is one of the most important, if not the most important issue, facing the province and the rest of the country.

> "It is one of the greatest issues of our time, inside Canada and outside Canada. So you know you are working on something that's vitally important and you know people are going to pay attention to what you produce."

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5.1.2 *CEMA Oil Sands Bibliography Enhancements – Kyle Harrietha, Cumulative Environmental Management Association*

OSRIN partnered with the Cumulative Environmental Management Association (CEMA) to enhance and update CEMA's Reclamation Research Database – renamed as the Oil Sands Environmental Management Bibliography. The bibliography will continue to be enhanced with additional references added to it on an ongoing basis.

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5.1.3 *Develop Website Structure – James Murgatroyd Communications*

The web designer converted the web portal design into a functioning website.

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5.1.4 *Digitizing Historical Oil Sands Research Reports*

OSRIN digitized historical oil sands related government-sponsored research work from the Alberta Oil Sands Environmental Research Program (218 reports – http://hdl.handle.net/10402/era.17505) and the Reclamation Research Technical Advisory Committee (41 reports – http://hdl.handle.net/10402/era.17506) and placed them on the University of Alberta's Education & Research Archive website to make information more readily accessible to stakeholders. These reports provide context and, in the case of the AOSERP reports considerable baseline information, to help stakeholders appreciate the depth and breadth of research undertaken since the mid-1970s to understand oil sands impacts and develop appropriate mitigation.

Other Government of Alberta reports have also been digitized to provide additional context (112 reports – http://hdl.handle.net/10402/era.22665). Seven historical Environmental Impact Assessment reports have also been digitized (http://hdl.handle.net/10402/era.38903).

Finally, 61 research reports from Syncrude Canada Ltd. spanning the mid-70s to the mid-80s were digitized (http://hdl.handle.net/10402/era.40201).

The reports are placed on the University's Education & Research Archive in .pdf format and are publicly available

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5.1.5 *iGEM Competition Sponsorship – Bob Mitchell, ConocoPhillips Canada*

OSRIN, in partnership with the Oil Sands Leadership Initiative, funded awards to international teams competing in the oil sands challenge portion of the iGEM competition in 2010, 2011 and 2012. iGEM stands for International Genetic Engineered Machines – a synthetic biology competition that uses standard biological "parts" in a kit to build biological systems that operate in living cells. These systems can perform any number of functions – in the oil sands challenge it is to develop efficient and effective oil extraction and environmental management tools.

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5.1.6 *iGEM Oil Sands Awareness Project – OSRIN in partnership with the Oil Sands Leadership Initiative (OSLI)*

About 30 students and faculty advisors from University of Alberta, University of Calgary, and University of Lethbridge were given tours of Suncor Millennium Mine and ConocoPhillips

Surmont in-situ project to familiarize them with challenges and opportunities for solutions using synthetic biology. The tour was used to set the stage for the 2010 competition.

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5.1.7 *Innovation Asset Database – UofA MBA Students*

Two MBA students prepared a searchable database of people working on oil sands land reclamation that has been placed on the OSRIN website.

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5.1.8 *Investigating a Knowledge Exchange Network for the Reclamation Community – Alberta Innovates - Technology Futures*

Report: Alberta Innovates – Technology Futures, 2012. Investigating a Knowledge Exchange Network for the Reclamation Community. OSRIN Report No. TR-26. 42 pp. http://hdl.handle.net/10402/era.28407

Abstract: Alberta Innovates – Technology Futures (AITF) and other parties have been investigating reclamation research, development and deployment capabilities and capacities in the province for several months. The concept of a 'Reclamation Centre' was first discussed through a Challenge Paper distributed in August 2011 to a variety of participants in the reclamation community.

The original key challenge was to engage the reclamation community in a dialogue to determine the benefits of forming a 'Reclamation Centre' in the Edmonton area. We obtained feedback from researchers, practitioners, regulators and other individuals and organizations who are interested in reclamation. The response from the participants clearly articulated that there was no need for additional reclamation research capabilities in central Alberta (e.g., greenhouses, buildings and other infrastructure). However, there was a need for a central point for collection and distribution of knowledge, information and data related to reclamation activities.

A Knowledge Exchange Workshop was held in Red Deer on February 29th, 2012. It focused on centralization, collection, distribution and synthesis of knowledge, information and data related to reclamation.

The workshop was used to answer a series of questions identified by the steering committee around knowledge exchange and the aspects of "What" (what kind of information, data, knowledge to share, etc.); "Why" (why would the community benefit from shared information, etc.) and "How" (type of format used to share the information, etc.). The intention was to have multiple stakeholder groups represented by the participants and to distribute them evenly throughout the room during the discussion to stimulate insightful, constructive and comprehensive conversation. The desired outcomes were:

1. To gain an understanding of what the reclamation community needs (wants) in terms of information, knowledge and/or data;

2. To gain an understanding of why the reclamation community wants this information and how they intend to use it;
3. To obtain suggestions on how to best achieve this and ways to move forward.

It became obvious from the table discussions that to be successful, this initiative requires involvement from the entire reclamation community. This includes service/consulting organizations, oil and gas, mineable and in-situ oil sands, sand, gravel and other mining industries, academia, government, and applicable associations such as CLRA, ESAA, AIA, PTAC, etc. All of these industries and organizations have a role to play in collaboration within the reclamation community.

Overall the participants found the question of why access to information, knowledge and/or data would be helpful and who would utilize it, easier to address than specifically 'what' needed to be shared and how to share it. However, evidence of the potential benefits of a knowledge exchange initiative for the reclamation community is compelling enough to warrant further exploration of the concept.

Overall the conclusions from the discussion indicated the reclamation community was interested in multiple types of information and knowledge that could be shared through different mechanisms. The information required was a hierarchy of quality, from peer reviewed literature and knowledge to broadly defined grey literature and most importantly anecdotal practitioner experiences. A main desire is to have greater access to information, but also to the people who generated the information.

There were several challenges associated with this type of an initiative related to how the information would physically be shared and how to encourage more effective collaboration in the broader reclamation community. The participants concluded the information should be shared through a variety of mechanisms.

Although challenges were identified, the most important obstacles to overcome are to clearly identify the benefits for multiple users, determining a funding mechanism and how to get started. The issues associated with information and computing technologies (ICT) and large databases, intellectual property, QA/QC in data quality, privacy, links to other organizations, etc. could be resolved during the process.

Although there was agreement that the concept of exchanging information, knowledge and/or data within the entire reclamation community was feasible, it was determined that the scope and intent of the initiative must be clearly articulated to answer key questions such as who will do the work, what will it cost and who will participate. It was suggested to start the initiative small and grow it appropriately with well-developed and clearly defined goals.

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5.1.9 *Media Monitoring Project – Troy Media Corp.*

This project evaluated the viability of a system to track media content relevant to OSRIN. Specific tasks included:

- Track media coverage of environmental issues associated with the oil sands, especially as it relates to some key issues (tailings ponds, water quality, land remediation, methane and CO_2 emissions)
- Prepare monthly Media Clip Books, which consist of all media hits
- Prepare monthly Media Metric Reports

The project ended when it became apparent that most media hits were not related to OSRIN's mandate.

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5.1.10 *Oil Sands Rules, Tools and Capacity: Are we Ready for Upcoming Challenges? – OSRIN*

Report: Oil Sands Research and Information Network, 2014. Oil Sands Rules, Tools and Capacity: Are we Ready for Upcoming Challenges? OSRIN Report No. TR-53. 120 pp. http://hdl.handle.net/10402/era.39985

Abstract: Within the next decade we are likely to see some significant tests of the current oil sands regulatory and policy framework, including:

- **Industry-driven:** such as an application for reclamation certificate or an application for release of process-affected water or a request to approve the water-capped fine tailings option
- **Government-driven:** such as the implementation of the tailings management framework or LARP management frameworks or the wetlands policy or AEMERA
- **Environment-driven:** such as a low-flow event in the Athabasca River or a major rainfall/flood event

What other challenges can we foresee?

We know there are various policy initiatives underway that will address some of these challenges but the results are not yet public and the related uncertainty is itself a challenge.

In this Workshop, held October 27, 2014 at the University of Alberta, 48 people from a number of sectors explored our level of readiness to deal with such challenges, based on our existing and planned rules, tools and capacity and identify solutions to address the challenges. Each table was asked to produce a list of potential challenges, categorize them based on a set of criteria and then provide solutions to the most pressing challenges.

About 84% of the challenges identified were expected to occur in the next 5 years; many of the challenges were described as happening right now. A total of 17 challenges were placed in the Parking Lot. Participants indicated we have Low Readiness to address 41% of the challenges;

the small number of High readiness challenges is probably a reflection of our tendency to focus on problems rather than things that are going well. Knowledge was the most frequently identified gap while Regulation was least commonly flagged.

Common themes among the 138 challenges include:

- Oil sands process-affected water release – criteria, process, stakeholder acceptability, pit lake viability, treatment options and costs
- Caribou – how to protect the species and its habitat; how to restore habitat
- Aboriginal – what are their desires and needs; how can we accommodate those needs into plans and operational practices
- Greenhouse gas and climate change – management, reduction, impact of regulation
- Climate change adaptation – how do we ensure hydrology and reclamation plans take climate change into account
- Closure and reclamation goals and reclamation certification – end land uses, is perpetual care an option, do we know how reclamation success will be measured
- How can offsets be used to compensate for disturbance
- Communicating with stakeholders – how to provide and explain complex data, how to explain plans, options and constraints
- Economic forces affecting development – access to market, access to resources, price of oil, liability management programs

Some of the key themes were:

- Desire to see clearer roles and responsibilities for government agencies in regulation, monitoring and communication; suggestions for a single *coordinator* for these roles
- Complete and implement all the Lower Athabasca Regional Plan frameworks
- More emphasis on technical- and risk-based decision-making
- More emphasis on *regional* outcomes and solutions
- More emphasis on obtaining, considering and incorporating Aboriginal views in plans and decisions
- Use adaptive management based on forecasts, scenarios, and monitoring
- Need more public, stakeholder and investor communication – share success stories (but acknowledge the problems), identify champions who can take the message out
- Invest in research, knowledge/data management
- Invest in skills training

- Retrieve, preserve and use historical knowledge and corporate memory

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5.1.11 *Support to Innovation Asset Database Project – Stephen Murgatroyd, Murgatroyd Inc. Communications and Consulting*

Murgatroyd was contracted to:

- Coach, guide and mentor the MBA students with respect of developing an asset map or set of maps.
- Related to your key issue(s).
- Provide technical help in the design of such a map.
- Oversee and support the development of the written document summarizing the available assets and identifying gaps.
- Seek out web based resources that would support the work of the MBA students.

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5.1.12 *University of Alberta iGEM Team Sponsorship – Dr. Mike Ellison, University of Alberta*

OSRIN, with support of ConocoPhillips Canada Resource Corp., is also directly funding the University of Alberta's iGEM Team to allow them to participate in the November competition. The Team is developing an inexpensive, self-contained kit that allows for faster and more efficient construction of DNA, thereby enabling broader access to biotechnology by the public. This innovation will help future development of oil sands-specific modules.

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5.1.13 *Web Portal Design – Stephen Murgatroyd, Murgatroyd Inc. Communications and Consulting*

The consultant helped design the OSRIN web portal, in conjunction with the website structure designer, as a reliable, highly respected and independent information portal in which all essential information about the oil sands environmental issues/actions are documented in an effective way.

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6 SOCIAL, ECONOMIC AND REGULATORY PROGRAM

This program seeks to identify social, economic and regulatory issues that may affect environmental management of the oil sands reclamation and to evaluate the effectiveness of environmental management in addressing social, economic and regulatory issues.

Project	Researcher
Completed Projects	
Accounting Reporting Standards	Dr. Thomas Schneider, University of Alberta
Alberta Energy Challenge	Commerce Energy & Environment Group, University of Alberta
Audit Protocol to Support Implementation of the Mine Financial Security Program	Richard Dixon, University of Alberta
Canadian Oil Sands Symposium	OSRIN, Embassy of Canada in Sweden, NEI Investments and Ethix SRI Advisors
DCM Survey of Albertan's Value Drivers	Satya Das, Cambridge Strategies Inc.
Factors to Consider in Estimating Oil Sands Plant Decommissioning Costs	Mark Morton Sr., WorleyParsons
How Qualifying Environmental Trusts Work as Reclamation Security	Richard Dixon, University of Alberta
Impacts of Changing Environmental Requirements on Oil Sands Royalties	Elis Valera, University of Alberta
Implications of Corporate Certification on Reclamation Security Estimates	Benjamin Thibault, Pembina Institute for Appropriate Development
Oil Sands Then and Now: How the Dialogue has Changed	Janice Paskey, Mount Royal University
Plain Language Explanation of Human Health Risk Assessment	Dr. Mohamed Gamal El-Din, University of Alberta
Review of Environmental Responsibility for Oil Sands Developments under Federal Legislation	Dr. Michael Howlett, Simon Fraser University
Review of Health Effects of Naphthenic Acids	Dr. Warren Kindzierski, University of Alberta

6.1 Completed Projects

6.1.1 *Accounting Reporting Standards – Dr. Thomas Schneider, University of Alberta*

Report: Schneider, T., 2011. Accounting for Environmental Liabilities under International Financial Reporting Standards. OSRIN Report TR-9. 16 pp. http://hdl.handle.net/10402/era.22741

Abstract: Recent reports from environmental non-governmental organizations (ENGOs) such as the Pembina Institute and the Environmental Law Centre in Canada, as well as investor groups such as Ceres and The Ethical Funds Company, have addressed the growing concern over environmental liabilities related to operations in Alberta's oil sands (Lemphers et al. 2010, Reuter et al. 2010, The Ethical Funds Company 2008, Watt 2010). Furthermore, environmental obligations are beginning to take a real bite out of the financial statements of firms operating in this sector. For example, a recent Globe and Mail article (Taylor 2010) on the owner of the largest single share in the Syncrude operation, Canadian Oil Sands Trust, notes that the almost $1 billion in spending next year it has allocated to its plants are primarily for moving equipment around and meeting environmental obligations, rather than improving plant efficiencies (Canadian Oil Sands Trust 2010).

Concurrent to this is a change in the accounting rules for Canadian public companies. Canadian public companies are in the process of moving from reporting under old Canadian Generally Accepted Accounting Principles (GAAP) to International Financial Reporting Standards (IFRS), which is now officially Canadian (public company) GAAP. This transition must take place for fiscal years ending after December 31st, 2010; which means that the first quarter financial reports for 2011 will be based on IFRS. This will include comparative information as it pertains to 2010.

With the move to IFRS, one of the key areas affecting firms in extractive industries pertains to the accounting rules by which environmental liabilities are accounted for. For firms in these industries, environmental matters play a major role in operations. The change in accounting rules will have a material effect on the total amount of environmental liabilities reported and the way in which they are expensed over time. I expect that under IFRS, more environmental liabilities will be recognised in the financial statements of firms operating in extractive industries, such as oil and gas and mining. However, there are certain mitigating factors that may be strong enough such that we see no significant increase in the reported environmental liabilities of these firms. The actual settling of these liabilities will occur in the coming decades. Under old Canadian GAAP and IFRS, these liabilities are recognised in the financial statements based on their present value. This is typically done by using a discount rate and the usual methods of calculating the present value of a future obligation. The new IFRS rules are very sensitive to the discount rate used and there is some debate as to exactly how the new discount rate should be calculated. Thus, although the new accounting standards under IFRS dictate that more specific environmental liabilities be recognised in the financial statements, this may be offset by changes in the way that they are quantified. This report discusses the potential impact the move to IFRS is expected to have on firms with mining operations in Alberta's oil sands. It details the changes in accounting methods and the potential impact on these firms with regards to the reporting and expensing of environmental liabilities. The discussion can be generalized to the overall oil and gas and mining sectors. However, the significant environmental challenges that are faced by the handful of firms mining in Alberta's oil sands make the move to IFRS an interesting one to follow.

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6.1.2 *Alberta Energy Challenge – Commerce Energy & Environment Group (UofA)*

OSRIN supported the 3rd annual Alberta Energy Challenge at the University of Alberta. The Challenge was a four-day interactive case competition focused on the energy sector, held September 27 – September 30, 2012. This year there were eleven teams competing at the University of Alberta, from across Canada, the United States, and one from the Middle East. Using the extensive resources provided to them and their own knowledge the teams had the opportunity to present innovative and engaging solutions to problems facing our energy sector. The 2012 Challenge is described below.

Transportation Deficit in Oil Sands Development

With the third largest oil reserves in the world, and the largest that are available for private development, the Alberta oil sands are attracting significant investment. Over the last ten years industry has invested $116 billion in oil sands development, and this investment is currently projected to increase by an additional $218 billion over the next 25 years. Further, this investment will raise bitumen production from its current levels of 1.75 Mbbl/day to a potential 5.0 Mbbl/day by 2035.

To achieve this level of growth, there are significant logistical and operational challenges to overcome. There are increasing problems with getting the needed materials and labour up to the sites; the rapidly increasing production is also straining the ability to get the hydrocarbons, along with their associated by-products and wastes, out of north eastern Alberta. The immense size, remote locations, extreme weather conditions, labour shortages, evolving technologies, ultra large equipment and infrastructure, social license approval, and environmental concerns also drive this issue.

In the face of all these challenges, it is clear that the transportation infrastructure in Northern Alberta needs to be improved.

- Context
- Innovative ideas have surfaced over the years to address the bottlenecks in oil sands supply logistics created by remote locations with relatively limited existing supply infrastructure.
- Oil sands developments are spread out over a large area of the north eastern part of the province (there are additional developments in the Peace River region but these will not be considered in this Challenge).
- In-situ operations are spread out over a much larger area than mining projects.
- The remote locations and the biophysical environment, including specifically significant areas of wetlands and major rivers, create challenges for infrastructure development.
- There are currently two major highways and one railway providing service to the region.
- Some companies have developed private airstrips.
- In-situ operations have different supply logistic requirements than mining projects.
- Development of Alberta's oil sands will occur over many decades.

- Forecasted oil sands production is greater than the current capacity to export oil from western Canada.

Tasks

1. Research and identify critical transportation bottlenecks that are currently, or may potentially, reduce operational efficiency and growth of the oil sands. (The focus of this task is on the logistics and operations of the oil sands. For example, from the Four-Access Framework this Challenge is more concerned about access to the natural resource at an operational level than access to the markets (e.g. Keystone XL, Gateway, etc.) The geographic area of concern is the corridor between Edmonton and the mining and in-situ sites in north eastern Alberta.)
2. From this research determine one or two key bottlenecks and give rationale for your choices.
3. Provide solutions to mitigate these bottleneck(s). Solutions should be feasible and sustainable with a focus on optimizing economic growth, reducing the environmental footprint, and improving public and worker safety.

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6.1.3 *Audit Protocol to Support Implementation of the Mine Financial Security Program – Richard Dixon, University of Alberta*

Report: Dixon, R.J., J. Kenney and A.C. Sandilya, 2012. Audit Protocol for the Mine Financial Security Program. OSRIN Report No. TR-27. 27 pp. http://hdl.handle.net/10402/era.28514

Abstract: The Audit Protocol for the Mine Financial Security Program was commissioned to provide a framework to assist government or third-party auditors of Annual Reports under Alberta Environment and Sustainable Resource Development's Mine Financial Security Program (MFSP). The Audit Protocol seeks to assist in the verification of the information provided to Alberta Environment and Sustainable Resource Development under the MFSP by coal and oil sands mine companies.

The Audit Protocol was prepared based upon the requirements of the *Mine Financial Security Program Standard* and the *Guide to the Mine Financial Security Program*, with reference to accepted auditing standards and defined reclamation requirements. The Audit Protocol has been designed to systematically enable an auditor to review and assess an Approval Holder's MFSP Project's:

- MFSP Assets (e.g., reserves);
- MFSP Liabilities (e.g., closure and reclamations costs);
- Reporting requirements;
- Base Security Deposit;
- Operating Life Deposit;

- Asset Safety Factor Deposit; and
- Outstanding Reclamation Deposit.

For each section of the MFSP Audit, a series of questions are presented to direct the auditor to the required information supporting the MFSP Annual Report.

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6.1.4 *Canadian Oil Sands Symposium*

OSRIN, in conjunction with the Embassy of Canada in Sweden, Ethix SRI Advisors and NEI Investments held a virtual workshop to connect speakers at the University of Alberta with an international audience of large investment firms in Stockholm, Sweden.

In Alberta, a panel of speakers from the Pembina Institute, Canadian Oil Sands Trust, Royal Society of Canada, Natural Resources Canada, Alberta Environment and Water, and Alberta Intergovernmental, International and Aboriginal Relations provided a brief overview of the issues and actions each is taking with respect to oil sands development. The Panel then responded to questions posed by the Stockholm audience, which focused on the implications of the proposed EU Fuel Directive, tailings ponds, health effects, greenhouse gases and pace of development.

Click here for background information provided to the Symposium participants.

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6.1.5 *DCM Survey of Albertan's Value Drivers – Satya Das, Cambridge Strategies Inc.*

Report: Chapman, K.J. and S.B. Das, 2010. Survey of Albertans' Value Drivers Regarding Oil Sands Development and Reclamation. OSRIN Report TR-3. 13 pp. http://hdl.handle.net/10402/era.17584

Abstract: A random sample of 1,032 Albertans, aligned with the Statistics Canada 2006 demographic profile of the Province of Alberta, completed an on-line survey with two elements: a conjoint best-worse survey, and a set of attitudinal questions. The goal of the CSI-OSRIN Oil Sands Survey (the survey) was to gather empirical information as a basis for oil sands policy development for both industry and government.

In contrast with conventional opinion polling, conjoint surveys force respondents to make trade-offs among sets of alternatives. The choices available in the alternatives presented are randomly generated by a computer program, and presented several times in different combinations. The consistency and tenacity with which respondents make certain choices over others enables the conjoint survey to determine the core values and principles that are most important. To think of it another way, the top choices become the essence of both a social license to operate for industry and the consent of the citizenry to be governed. In effect, they indicate which aspects of oil sands stewardship and development are most negotiable, and which are least negotiable, when it comes to responding to the public's expectations.

Compared with conventional opinion polling, a conjoint survey is a more accurate indicator of actual preferences and a more precise determinant of behaviours. The survey therefore identifies the priorities of perceived values, performance and aspirations around responsible and sustainable oil sands development. We hope this survey can be an empirical foundation of any public policy design, development and deployment regarding the oil sands. The results offer a clear understanding of public expectations.

The survey found that the top three drivers related to development and reclamation of oil sands were: Type of reclamation (20%), Wildlife habitat (19%) and Ecological monitoring (18%). There is significant consistency in priority choices between these 2010 survey data and a similar study CSI conducted in 2007 (Chapman et al. 2009) on the values and priorities of Albertans with regard to responsible and sustainable oil sands development. Based on the priority preferences as to what should guide and drive oil sand development this survey result shows where action is needed and communications should be focused.

The survey then looked at how Albertans perceive issues are being addressed.

- For the **type of reclamation** driver 31% believe that the focus is on reclamation to sustain wildlife and biodiversity while 23% believe it is to return land to a “state of nature”. Surprisingly 21% believe that reclamation is about letting nature take its course (i.e., no reclamation).
- For the **wildlife habitat** driver 78% believe that there is some wildlife habitat protection when developing oil sands, 16% believe there is no protection and 6% believe there is full protection.
- For the **monitoring ecological impacts** driver 47% of Albertans believe government is doing the monitoring, 36% believe industry is and 11% thought it was done by a third-party. Only 6% felt there was no monitoring done.

Perceptions around reclamation indicated that Albertans expect government to set the rules, regulations and define best practices for reclamation and the companies operating in the oil sands should then take the lead for reclamation responsibilities. 78% of survey participants completely agreed or agreed with this position, while 16% slightly agreed. Only 6% disagreed with this to one degree or another.

When asked if companies operating in the oil sands should be solely responsible for reclamation the survey found that 69% of participants completely agreed or agreed with this position and 16% slightly agreed. There were 15% who disagreed with this position to some degree or other.

When queried if oil sands companies should be held liable for all environmental damages caused by their operations the survey found 87% completely agreed or agreed with this position, 9% slightly agreed and only 4% had some level of disagreement with this approach.

When asked about perception on how well the Alberta government is responsibly managing the oil sands resource 31% agreed or completely agreed they were doing the job and 18% disagreed or disagreed completely. There was a significant swing group of 51% in the middle – 34% who slightly agreed the government was responsibly managing the oil sands and 17% slightly disagreed.

Most of the choices people identified as important to them coincide with the current state of oil sands development and management. However there were some key attributes where there was a clear difference. These attributes represent the areas where government and industry risk loss of the social licence to operate unless further work is done to address the misalignment between what people perceive is happening and what is actually happening. Work in these areas could include better communication of the current state and why it is appropriate or what is being done to correct the current state if it is inappropriate.

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6.1.6 *Factors to Consider in Estimating Oil Sands Plant Decommissioning Costs – Mark Morton, Sr., WorleyParsons*

Report: Morton Sr., M., A. Mullick, J. Nelson and W. Thornton, 2011. Factors to Consider in Estimating Oil Sands Plant Decommissioning Costs. OSRIN Report No. TR-16. 62 pp. http://hdl.handle.net/10402/era.24630

Abstract: This report provides a number of cost estimating factors, common terminology and common practices derived from industrial decommissioning projects, international cost estimating practices and the outcome of a joint university, industry and regulator workshop. The cost estimation factors identified in this report represent common practice in the decommissioning industry and are intended to cover the key cost components for a detailed oil sands plant decommissioning cost estimate. This report also identifies factors that may affect the reliability of the estimates (i.e., the level of uncertainty and therefore an indication of the contingency factors that may need to be applied to the estimate).

Significant factors contributing to a detailed oil sands facility Mine Financial Security Program (MFSP) Liability project cost estimates include:

- Scope Definition
- Assumptions
- Basis of Estimate
- Site Environmental Assessment(s)/Physical Plant/Residual Materials/Hazards
- Shutdown/Isolation/Hazards Removal
- Demolition/Dismantling/Salvage/Recycle
- Remediation/Decontamination
- Risk Analysis
- Long Term Monitoring
- Liability Estimate Revisions

The intent of this document is to supplement the existing guidance on the content of the MFSP Liability value that is in the *Guide to the Mine Financial Security Program*. The report *does not*

prescribe what needs to be included at any point in the Approval Holder's MFSP estimate. Included in the report are the things one should consider at some point in the life cycle of the oil sands plant (especially close to the time the Operating Life Deposit is made) and some information on the methodology and accuracy of estimates. Similarly, the intent is not to prescribe when the Approval Holder chooses to include increased detail or accuracy to the estimates – this is the Approval Holder's decision. The report does offer suggestions (e.g., estimate methods, content, and when and why the accuracy of the estimate might be updated, etc.) to assist in developing an estimate.

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6.1.7 *How Qualifying Environmental Trusts Work as Reclamation Security – Richard Dixon, University of Alberta*

Report: Dixon, R., M. Maier, A. Sandilya and T. Schneider, 2012. Qualifying Environmental Trusts as Financial Security for Oil Sands Reclamation Liabilities. OSRIN Report No. TR-24. 32 pp. http://hdl.handle.net/10402/era.28305

Abstract: The Alberta oil sands resource is vast; however, the amount that can be accessed via open-pit mining is limited. The process of extracting oil from bitumen via open-pit mining has now been going on for decades and could be considered a mature industry. Under Alberta law, plans for the suspension, abandonment, remediation and surface reclamation of each oil sands mine and associated processing plant must be in place before the government allows mining to take place. Each operator must also provide some form of financial security to the Government of Alberta to ensure that funding will be in place to pay for suspension, abandonment, remediation and surface reclamation liabilities, in the event that the Approval Holder is unable or unwilling to do so. As a mine approaches its end-of-life, the Approval Holder must increase the amount of financial security provided to Alberta Environment and Sustainable Resource Development, such that by the time the mine has less than six years of reserves left, the entire amount of the estimated clean-up cost is covered by financial security. One of the forms of financial security made available to oil sands operators, effective 2011, is a qualifying environmental trust (QET).

The royalty regime in Alberta for operators of mature oil sands mines (known as the post-payout phase) is such that royalties paid by oil sands operators to the government are calculated based on revenue less 'allowed' costs. Abandonment, remediation and surface reclamation costs are considered allowed costs. However, an Approval Holder cannot deduct allowed costs from royalties after bitumen production is complete; thus any suspension, abandonment, remediation and surface reclamation costs incurred after production are not deductible. On the other hand, the funding of a QET to provide financial security for future suspension, abandonment, remediation and surface reclamation costs is immediately deductible for royalty and income tax purposes. For reasons detailed herein, we expect that as oil sands mines approach their end-of-life, the operators will establish QETs to avoid forfeiting the deduction of their suspension, abandonment, remediation and surface reclamation costs. The suspension, abandonment,

remediation and surface reclamation liabilities that have accrued to the oil sands operators are now in the billions of dollars. If even a portion of these are funded by QETs, the effect on the amount of royalties and taxes flowing to the Government of Alberta will be in the hundreds of millions of dollars. Thus, understanding if and when oil sands operators will choose to use QETs is important for the forecasting of government revenues, particularly as oil sands royalties are now the single biggest contributor to Alberta's total royalty revenue.

It should be noted that a QET provides a very strong form of financial security. Various versions of environmental trusts are available to mining companies in jurisdictions throughout the world. They are generally deductible for tax purposes; however, we find almost no use of them anywhere, including other jurisdictions within Canada. In this report we discuss why we believe that oil sands firms will use QETs as the reserves in their mines run down. This is done in the context of Alberta Environment and Sustainable Resource Development's Mine Financial Security Program, introduced in 2011, and the fact that the end-of-life of a number of oil sands mines are in the not too distant future.

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6.1.8 *Impacts of Changing Environmental Requirements on Oil Sands Royalties – Elis Valera, University of Alberta*

Report: Valera, E. and C.B. Powter, 2012. Implications of Changing Environmental Requirements on Oil Sands Royalties. OSRIN Report No. TR-23. 21 pp. http://hdl.handle.net/10402/era.27344

Abstract: Environmental requirements for oil sands operations have increased over time and are likely to continue to do so. Oil sands operators are responsible for the costs associated with meeting environmental requirements prescribed by the government. However, the province's oil sands royalty regime incorporates deductions for *allowed costs* which include costs of meeting environmental requirements. Therefore, in effect, increasing environmental requirements, which often mean greater costs, results in reduced government royalties.

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6.1.9 *Implications of Corporate Certification on Reclamation Security Estimates – Benjamin Thibault, Pembina Institute for Appropriate Development*

Report: Thibault, B., 2012. Assessing Corporate Certification as Impetus for Accurate Reporting in Self-Reported Financial Estimates Underlying Alberta's Mine Financial Security Program. OSRIN Report No. TR-29. 37 pp. http://hdl.handle.net/10402/era.29361

Abstract: Alberta's Mine Financial Security Program (MFSP) establishes the procedures for determining and administering financial security for reclamation of oil sands and coal mining operations. The program establishes more transparent and consistent methods for determining the financial security amount required to cover the mine's suspension, abandonment, remediation and surface reclamation liabilities should the operator fail financially – while considering the

value of the resource as assets against the liabilities. For oil sands mining operations, total MFSP liabilities can run in the hundreds of millions of dollars.

To determine financial security amounts, mine operators self-report estimates of the liabilities and assets in the operation. Accuracy of the asset and liability estimates is important to provide public assurance that the program is providing appropriate levels of financial security. Within the MFSP, certain mechanisms are used to improve regulator and public confidence in the accuracy of these estimates. Under analysis here is the corporate certification requirement: a high-level representative – either the Chief Executive Officer (CEO) or Chief Financial Officer (CFO) of a corporate mine operation or a designated financial representative (DFR) of a joint venture – must certify that appropriate procedures were used to determine the estimate values and that the estimates are reasonable.

By investigating the legal and regulatory setup for the MFSP, this paper assesses the expectation of increased confidence from the certification requirement by describing its legal implications and the impetus it places on corporations to ensure appropriate procedures for generating estimates.

In short, the corporate certification requirement ensures documentary evidence of officer involvement in any misreporting by mining operators. For any misreporting that constitutes an offence under the governing legislation – the *Environmental Protection and Enhancement Act* (EPEA) – this could raise individual officer liability under the Act. EPEA has enforcement provisions to penalize misreporting under the MFSP, which can be applied to companies as well as individuals. The individual penalties, which can include imprisonment or monetary penalties, can be applied to a corporate officer where he or she had some minimum level of involvement in the misreporting.

With respect to some of the most important estimates, there is a link between the MFSP calculations and values reported under disclosure obligations in securities law. This is another mechanism for improving regulator and public confidence in the MFSP estimates and includes a similar certification requirement. While the effectiveness of this mechanism is not within the scope of this analysis, it provides a comparator against which to analyze the effectiveness of the MFSP corporate certification requirements, particularly in terms of the penalties available under each regime.

In light of the relatively small magnitude of the monetary penalties available under EPEA and important barriers to investigation and enforcement of misreporting violations, the extent to which certification requirements incent better estimate procedures is not clear. This is particularly true given the small penalties under EPEA relative to those available under securities law. Nonetheless, the risk of reputational injury could provide a less formal but still very powerful incentive that certification bolsters by demonstrating officer involvement. Unfortunately, the absence of a role for civil society in the scrutiny of the estimates precludes a potentially stronger role for certification to incent enhanced estimate veracity.

In conclusion, there is some expectation that the inclusion of the MFSP certification requirement provides an incentive for better procedures for asset and liability estimation in the MFSP Annual Report. It is difficult to assess the strength of this incentive, particularly because of uncertainties around the capacity to investigate reporting misconduct with respect to complex internal accounting procedures, on which the enforcement and, in turn, certification requirements rely for effectiveness. A few more conclusions are discussed further.

First, there is a lack of clarity in industry around the potential for liability against the certifying authority arising from certification. This can have two negative consequences. For one, the potential liabilities that do exist are not having their full deterrent effect if they are not properly understood by the actors they are intended to impact. Also, reduced certainty with respect to any business decision, but particularly for potential monetary and imprisonment penalties, can undermine efficient business behaviour and lead to suboptimal policy results. This can be improved by:

- more clearly explaining how individual liability attaches from the certification;
- providing concrete hypothetical examples of misreporting infractions that can lead to individual officer liability; and
- better linking the "effect" (wording) of the certification statement to EPEA's standards for individual officer/agent liability.

Second, it is not clear what internal capacity or threshold triggers Alberta Environment and Sustainable Resource Development (ESRD) employs to initiate a more concerted governmental audit or third-party audit of an MFSP Annual Report. The effectiveness of these procedures is critical to the mechanism through which certification engages potential legal liabilities or reputational costs for certifying authorities. Uncertainty around ESRD's capacity or procedures for pursuing more concerted investigations undermines clarity around the certification's effectiveness. This can be improved by:

- providing more information to stakeholders around ESRD's review process and where and how ESRD chooses to exercise its audit powers and pursue enforcement measures; and
- establishing clearer presumptions or default values for certain parameters of asset and liability estimation, such as minimum per-hectare reclamation costs, derivation from which requires an explanation from the operator.

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6.1.10 *Oil Sands Then and Now: How the Dialogue has Changed – Janice Paskey, Mount Royal University*

Report: Paskey, J., G. Steward and A. Williams, 2013. The Alberta Oil Sands Then and Now: An Investigation of the Economic, Environmental and Social Discourses Across Four Decades. OSRIN Report No. TR-38. 108 pp. http://hdl.handle.net/10402/era.32845

Abstract: A detailed study of dozens of documents pertaining to the Alberta oil sands produced by the Alberta government over the past 40 years shows the government's perspective regarding this vast resource has undergone a major shift.

In the 1970s and early 1980s, the Alberta government initiated detailed studies and scientific investigations to better determine oil sands policy. By the mid-1990s documents suggest the government had abandoned that role in favour of promotion and marketing of the oil sands.

It is quite clear from government documents produced in the 1970s that most of the economic, environmental, and social impacts associated with rapid expansion of oil sands operations (often referred to as tar sands in the 1970s) were anticipated. Various studies and surveys were also undertaken by the government of the day to determine how to avoid these negative impacts.

For example, a 1973 Alberta Environment report – *An Environmental Study of the Athabasca Tar Sands* – states: "The disposal of tailings from the hot water extraction process represents the most imminent environmental constraint to the future expansion of this recovery method."

Documents reviewed suggest that at the time the Alberta government saw itself as being primarily responsible for further development of the oil sands. To this end, the government invested millions of dollars in the Alberta Oil Sands Technology and Research Authority (AOSTRA) to kick start expansion. AOSTRA initiated and funded research into technological innovation for the extraction of bitumen. Another government agency – Alberta Oil Sands Environmental Research Program (AOSERP) – investigated social conditions for people living near oil sands plants and environmental impacts such as air emissions and tailings ponds.

By the mid-1980s the Alberta government had pulled back from this direct kind of involvement with oil sands development. And even though much research into environmental and social impacts had been carried out it was put on the back burner in favour of more immediate economic benefits.

This study also examined documents pertaining to the oil sands produced by industry, academia, non-governmental organizations, and the news media over the past 40 years during which time oil sands operations expanded from two to seven oil sands mining projects, 26 commercial in situ projects approved, in addition to about 130 primary recovery projects and 12 experimental schemes.

The study revealed that public discourse about the oil sands has shifted from one that was primarily focused on the economic benefits of oil sands development to a conversation that involves a multiplicity of issues and voices.

Economic signifiers such as job creation, royalty revenues, foreign investment, and markets are still key when it comes to talking about the oil sands. But in the last 10 to 15 years, global issues such as climate change, indigenous rights, pollution of the air and major waterways, and sustainability have become embedded in the discourse about the oil sands. Nowadays, the oil sands are talked about as if they are an arena in which key players and issues vie for attention.

The entry of other voices into the discourse about the oil sands has also affected Canada's dialogue with the United States regarding oil exports. Whereas the United States was once discussed as the prime customer that must be satisfied at all costs, now governments and industry talk about the U.S. as a riskier market and seek to export the oil to China, India and other emerging markets as well.

There are some significant language choices that stand out in the media, particularly the distinction between "tar sands" and "oil sands." It has been suggested in media coverage that supporters for the development of this resource use the label "oil sands", whereas critics deploy "tar sands". While this claim rings true, in the media sample reviewed it becomes evident that "tar sands" was used during the 1980s and 1990s in a completely neutral way, simply in reference to the "Athabasca Tar Sands." "Tar sands" became a more negative term only when it is associated with vivid descriptors such as being a "monster" that "needs to be fed", or as the "black stain of Canada", or simply talked about as something "dirty", "sticky", "gooey", or "oozing." These types of expressions are most often used by Aboriginal sources, environmentalists, political figures (members of the opposition), and sometimes journalists themselves. These stakeholders deploy such terms when they want to criticize the development of this resource. In the sample of articles examined, it was not until 2008 when the environmental action group Environmental Defence published *Canada's Toxic Tar Sands: The Most Destructive Project On Earth* that these types of negative add-ons started to appear.

All of the documents examined in the study were in English, as were the news articles. This is an admitted limitation as we do not capture dialogue in francophone Canada. Most of the documents collected and analyzed for this report came from a database established by the Cumulative Environmental Management Association (CEMA), a collaborative organization based in Fort McMurray, Alberta that includes representatives from government, industry, academia, First Nations, civic and community organizations, and environmental groups. Other documents were collected from university, government, industry and NGO libraries and databases. The news articles were collected from two databases – CBCA Complete and Canadian Newsstand.

Discourse about the oil sands is one of the most important conversations occurring in Canada and abroad. The deeper we can delve into that conversation, the more we can come to understand all the complexities, risks, and rewards that this vast resource presents to Albertans, Canadians and the world.

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6.1.11 *Plain Language Explanation of Human Health Risk Assessments – Dr. Mohamed Gamal El-Din, University of Alberta*

Report: Kindzierski, W., J. Jin and M. Gamal El-Din, 2011. Plain Language Explanation of Human Health Risk Assessment. OSRIN Report TR-14. 37 pp.
http://hdl.handle.net/10402/era.23487

Abstract: Many factors can affect a person's health, such as quality of life, how long they live, and whether or not they suffer diseases. These factors are referred to as *determinants of health*. The quality of environmental media related to oil sands developments in northeastern Alberta represents a concern to people at the local, national, and international level. The key determinants of people's exposure to chemical pollutants are: time-activity (where we spend time and what we do), interaction with indoor environments, diet, and occupation. In most instances these determinants explain most or all of what influences exposure to chemicals in the environment. One way to investigate the relationship between the quality of environmental media and human health risk is to perform a human health risk assessment (HHRA).

A human health risk assessment is an important component of most environmental impact assessments of new oil sands development projects. Human health risk assessment is also likely to be a key requirement for understanding potential human health impacts of the release of oil sands process-affected waters to the environment.

A human health risk assessment is the process of determining if a particular chemical or other hazard in the environment (e.g., particulate matter) poses a health risk to people for a specific set of conditions. People are called *receptors* in human health risk assessment. It is not possible to tell where in time and space people will actually be in relation to where chemical pollution exists, and therefore the extent to which they are actually exposed. Thus assumptions need to be made about their exposures to allow us to assess human health risk.

Human health risk assessments are prepared by professional consultants (scientists and engineers) for government, industry and other organizations. This is done to help decision makers, especially policy makers and regulators, understand potential health impacts from the release of chemical pollutants into the environment by industrial operations. This type of information – along with social, economic, and other information – can help to inform policy and regulatory decisions that help protect people from chemical exposures as a result of pollution.

Human health risk assessment procedures described here are normally accepted by regulatory agencies because they are, purposely, conservative. This conservatism makes it less likely to under estimate potential exposures and human risk and more likely that resulting regulatory decisions made will protect people from chemical pollution by industrial operations in real situations.

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6.1.12 *Review of Environmental Responsibility for Oil Sands Developments under Federal Legislation – Dr. Michael Howlett, Simon Fraser University*

Report: Howlett, M. and J. Craft, 2013. Application of Federal Legislation to Alberta's Mineable Oil Sands. OSRIN Report No. TR-33. 94 pp. http://hdl.handle.net/10402/era.31627

Abstract: This report examines the Government of Canada's legislation that may impact oil sands environmental management in Alberta. It focuses on the evolution, and current state of,

pertinent federal legislative Acts in the environmental, natural resource, and energy policy sectors. As detailed below, five Acts form the core of the review. A limited number of additional Acts, policies, and Canada-Alberta agreements are examined given their direct applicability to oil sands activity. In particular, the report focuses on descriptively setting out the implications and potential impacts stemming from recent legislative changes spurred by the passage of the 2011 and 2012 federal 'omnibus' budget implementation bills (Bills C-38 and C-45, respectively). These bills not only amended a large existing suite of legislation in the environmental, energy, and natural resources sectors, they also created *new* legislation with direct implications for oil sands environmental management. This report reviews and assesses these changes.

The five Acts that form the core of this examination are: the *Fisheries Act (FA, 1985)*, the *Canadian Environmental Protection Act* (CEPA, 1999), the *Canadian Environmental Assessment Act* (CEAA, 1999 and 2012), the *Species at Risk Act* (SARA, 2002), and the *Migratory Birds Convention Act* (MBCA, 1994). The study takes a 'project life cycle approach' to descriptively examine if, and how, federal legislation applies to oil sands environmental management in relation to (1) the pre-construction phase; (2) the operational phase; and, (3) the reclamation and post-certification phase.

The focus of this study is *exclusively* on federal legislation. However, the constitutional division of powers in Canada's federal system necessitates some attention to intergovernmental and multi-level governance issues. As such, the report includes a brief overview of federalism and its continued relevance for legislation in the environmental, natural resources, and energy sectors with a focus on environmental management.

Passed in 2011 and 2012, Bill C-38 and Bill C-45 are recent Acts and have yet to be subjected to few, if any, descriptive or analytical scholarly examinations. The dearth of studies is even more extreme from an environmental management perspective. This study therefore uses primary document analysis of the above listed Acts as its core method. This is supplemented with reference to secondary academic sources, Government of Canada policy documents and audits, media sources, access to information requests, and recent joint panel reviews conducted as part of the environmental assessment of some existing oil sands projects. Finally, a series of informal consultations were also conducted with senior federal officials from multiple departments to seek comment and clarification on the legislation examined and for technical clarifications as required.

The findings detailed in this study suggest that Bills C-38 and C-45 are watersheds in environmental and natural resources policy sector governance in Canada. The Acts fundamentally reorient the Government of Canada's approach to environmental regulation, Canada-Alberta environmental assessment processes and represent a clear shift towards greater Ministerial discretion for regulation under several Acts amended by the two omnibus budget implementation bills. The report documents that, from a federal perspective, only a few provisions in each of the Acts are directly applicable to environmental management. The general pattern identified in amendments is a clear attempt to devolve, delegate, and harmonize federal activity in the policy sector with the Government of Alberta. From a project life cycle perspective, federal legislation was found to be most pronounced at the pre-construction phase (front-end) through project applications for permitting under federal legislation and the environmental assessment processes. However the permitting and environmental assessment regimes reviewed also included some provisions requiring monitoring, reporting, and enforcement that have implications for the operational and reclamation and post-certification phases.

The current federal administration has made its explicit intention to reduce if not remove regulatory delay, duplication, and burden to expedite economic and resource development. As this report emphasizes, a review of pertinent legislation and consultations with government officials reveals a considerable degree of uncertainty remains related to environmental management. Not all new potential regulations under the amended budget implementation bills have been brought into force. In some instances, transitional provisions apply while in others regulations are expected but had not yet been publicly disclosed. As such, officials and official government documents were unclear as to their applicability to environmental management.

The report concludes that recent legislative changes have increased uncertainty related to the application of federal legislation to oil sands development. This is due to the lack of precedent by which to understand its application, and because not all regulations have been brought into force. The report concludes this uncertainty is particularly acute for the reclamation and post-certification phase because of the limited reclamation and certification that has occurred to date.

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6.1.13 *Review of Health Effects of Naphthenic Acids – Dr. Warren Kindzierski, University of Alberta*

Report: Kindzierski, W., J. Jin and M. Gamal El-Din, 2012. Review of Health Effects of Naphthenic Acids: Data Gaps and Implications for Understanding Human Health Risk. OSRIN Report No. TR-20. 43 pp. http://hdl.handle.net/10402/era.26060

Abstract: Oil sands mining involves removal of water from the Athabasca River basin in northeastern Alberta. Water produced during the extraction of bitumen from oil sands is referred to as oil sands process water (OSPW). Information on the likelihood of human exposure to OSPW-derived naphthenic acids and toxicological (dose-response) data are needed to have a complete understanding of the human health risk of these compounds. A review of literature was undertaken as a first step in framing potential human health risk associated with exposure to OSPW-derived naphthenic acids in surface water. Specifically, this review focused on chemical characteristics of, and potential toxicological effects related to, OSPW-derived naphthenic acids.

General Chemical Characteristics of Naphthenic Acid Mixtures in OSPW

There are several important findings of the review with regard to chemical characteristics of naphthenic acid mixtures in oil sand process waters:

- OSPW represents a complex mixture of naphthenic acids along with other organic chemicals that can also contribute to potential toxicity of the mixture.
- There is a difference in the distribution of organic compounds and their contribution to potential toxicity of OSPW that is fresh (i.e., OSPW recently produced from the oil sands extraction process) versus OSPW that is allowed to age (i.e., OSPW that has been aged for a number of years in inactive storage ponds or pit lakes). Aged OSPW contains higher molecular weight, multi-ring naphthenic acids that have been shown to be more resistant to microbial degradation and less potent in toxicity to biological organisms.
- An understanding of the forms and composition of OSPW-derived naphthenic acids and other organic compounds present in fresh and aged OSPW, and the effect of aging and aging environment on this composition, and variation in OSPW composition across oil sands processes is incomplete.

Human Exposure Evidence

OSPW-derived naphthenic acids are not used by the human population and the potential for human exposure in the oil sands region will arise from their presence in surface water or from potential future release of reclaimed OSPW to surface water. Based on the information reviewed, it was found that:

- Direct contact activities with surface water (e.g., ingestion and skin contact) represent a plausible way in which human exposure may occur to OSPW-derived naphthenic acids.
- Low water-to-air transfer properties and dilute concentrations of aged and reclaimed OSPW-derived naphthenic acids provide no meaningful scientific evidence to support the inhalation pathway as being important for potential human exposure.
- Low octanol water partition values and apparent rapid depuration of aged OSPW-derived naphthenic acids offer no meaningful scientific evidence to support the fish ingestion pathway as being important for potential human exposure to these compounds.

Toxicological Evidence

Toxicity information of interest for understanding human health risk from chemicals in the environment includes: acute toxicity, subchronic/chronic adverse responses (e.g., weight loss, immunosuppression, etc.), neurotoxicity, developmental and reproductive toxicity, and genetic toxicity (mutagenicity and carcinogenicity).

A general finding of this review is:

- Toxicological evidence observed for commercial naphthenic acids derived from crude oils and/or commercial naphthenic acid salts will not be representative of naphthenic acids in aged and reclaimed OSPW. Higher molecular weight, multi-ring naphthenic acids, which are more resistant to microbial degradation and less potent in toxicity to biological organisms, are the forms reported to be present in aged and reclaimed OSPW.

- OSPW-derived naphthenic acids come from bitumen which is considered to be extensively biodegraded petroleum, whereas commercial naphthenic acids are typically prepared from petroleum sources that have not undergone extensive biodegradation. Therefore, potential human toxicity and corresponding human exposure limits for OSPW-derived naphthenic acids should not be inferred from studies of commercial naphthenic acids.

Acute Toxicity

Naphthenic acids found within crude oils exhibit similar oral toxicity to table salt. Acute toxicity testing in rats revealed behavioral and histopathological effects from a single administration of OSPW-derived naphthenic acids, but at a dosage 50 times a worst case environmental exposure for small mammalian wildlife. This dosage is a not realistic exposure condition that would apply to humans in the oil sands region.

Subchronic/Chronic Noncarcinogenic Toxicity

A finding of this review is:

- Based upon limited information reviewed, uncertainty remains in the understanding of toxicokinetic (fate in the body) and toxicodynamic (mode of action and dose-response) information needed to infer noncarcinogenic human exposure-related responses to naphthenic acids and other acid-extractable organics present in aged and reclaimed OSPW.

A recommendation of this review is:

- There is a need to further examine potential subchronic/chronic toxicity of naphthenic acids and other acid-extractable organics present in aged and reclaimed OSPW.

Developmental and Reproductive Toxicity

A finding of this review is:

- Based upon limited information reviewed, uncertainty remains about knowledge of developmental and reproductive toxicity of naphthenic acids and other acid-extractable organics present in aged and reclaimed OSPW.

A recommendation of this review is:

- There is a need to further examine developmental and reproductive toxicity endpoints of naphthenic acids and other acid-extractable organics present in aged and reclaimed OSPW using *in vitro*/*in vivo* bioassay testing focusing on cellular response pathways.

Genetic Toxicity

A finding of this review is:

- Based upon limited information reviewed, uncertainty remains about knowledge of genetic toxicity of naphthenic acids and other acid-extractable organics present in aged and reclaimed OSPW.

A recommendation of this review is:

- There is a need to further examine genetic toxicity endpoints (including carcinogenic endpoints) of naphthenic acids and other acid-extractable organics present in aged and reclaimed OSPW using *in vitro* genetic (micronucleus) testing and/or other suitable tests focusing on cellular response pathways.

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7 STRATEGIC DESIGN

This program includes projects to help OSRIN establish and document its strategic intent, and research and communication approach. The products form the key tools to explain who we are and what we do.

Project	Researcher
Completed Projects	
Communication Input and Guidance with Challenge Dialogues	Simon Dyer, Pembina Institute
Communications Strategy Support	Janice Simpson, Redoaks Management Consulting Inc.
Develop OSRIN Strategy	Innovation Expedition Consulting Inc.
Launch of Knowledge Translation Program for the Proposed Alberta Centre for Reclamation and Restoration Ecology (ACRRE)	Dr. Ellen Macdonald, University of Alberta
Survey of Oil Sands Environmental Management Research and Information Needs	Oil Sands Research and Information Network

7.1 Completed Projects

7.1.1 *Communication Input and Guidance with Challenge Dialogues – Simon Dyer, Pembina Institute*

Pembina was contracted to provide guidance on communications regarding the Challenge Dialogues and to provide input to the design of the Dialogues.

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7.1.2 *Communications Strategy Support – Janice Simpson, Redoaks Management Consulting Inc.*

Redoaks Management was contracted to provide:

- Strategic orientation of web site
- Communications input and guidance with the Challenge Dialogue and subsequent reports
- Assistance with letters or documentation relating to the Oil Sands Research and Information Network (OSRIN) consultation with a variety of interest groups

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7.1.3 *Develop OSRIN Strategy – Innovation Expedition Consulting Inc.*

The project consisted of three phases:

- Phase 1 - Clarification of Strategic Intentions
- Phase 2 - Outcome Mapping
- Phase 3 - Identification of Key Indicators

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7.1.4 *Launch of Knowledge Translation Program for the Proposed Alberta Centre for Reclamation and Restoration Ecology (ACRRE) – Dr. Ellen Macdonald, University of Alberta*

Report: Alberta Centre for Reclamation and Restoration Ecology and Oil Sands Research and Information Network, 2014. Creating a Knowledge Platform for the Reclamation and Restoration Ecology Community: Expanding the OSRIN Model Beyond the Oil Sands. OSRIN Report No. TR-65. 19 pp. http://hdl.handle.net/10402/era.40323

Abstract: One of the core mandates for the Oil Sands Research and Information Network (OSRIN) was to enhance access to oil sands environmental management information. With OSRIN's mandate ending December 31, 2014 OSRIN sought a partner with a similar philosophy to provide an archive for the website content and to continue the role of knowledge generation, perhaps with a broader scope than the oil sands. OSRIN provided funding for the Alberta Centre for Reclamation and Restoration Ecology (ACRRE) initiative at the University of Alberta to develop an ACRRE website, which will house the OSRIN content, and to produce a series of knowledge exchange communications that will be used to demonstrate the business case for ACRRE, a knowledge generating and sharing program for the reclamation and restoration community.

Previous work conducted by OSRIN has demonstrated the strong desire, across a broad base of stakeholder groups, for increased access to timely research information. Stakeholders participating in OSRIN's workshops have also demonstrated this thirst for knowledge sharing opportunities.

Outreach and application of knowledge is a key component of ACRRE's mandate. ACRRE will connect scientists, practitioners, managers, regulators, and policymakers. Collaborative efforts within this network will focus on integrating, synthesizing, sharing and applying scientific knowledge to address challenges in land reclamation and restoration. The Faculty of Agricultural, Life and Environmental Sciences (ALES) at the University of Alberta and OSRIN have already provided proof-of-concept of the delivery of the Centre's outreach mandate. The delivery of the outreach program will be through: preparation of major synthesis and review papers on topics of particular importance to partners; creation of short, focused Research Notes synthesizing recent research results; delivery of technology transfer workshops, symposia, and conferences; and organization of field tours.

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7.1.5 *Survey of Oil Sands Environmental Management Research and Information Needs – Oil Sands Research and Information Network*

Report: Oil Sands Research and Information Network, 2014. Survey of Oil Sands Environmental Management Research and Information Needs. OSRIN Report No. TR-58. 67 pp. http://hdl.handle.net/10402/era.40128

Abstract: As one of its last projects, the Oil Sands Research and Information Network (OSRIN) conducted this survey of oil sands environmental management research and information needs. The survey was conducted in October and early November 2014 for OSRIN by the University of Alberta's Population Research Laboratory (PRL).

The survey content was developed by OSRIN. The PRL then placed the survey into digital format and provided a link to the survey site to OSRIN. The PRL provided the raw survey results in Excel format to OSRIN in November.

A link to the survey was originally sent to 276 people and 13 organizations via e-mail on October 31, 2014. The link was also placed in the October 31, 2014 edition of the OSRIN Newsletter which was distributed to 273 people, with a reminder in the November 14 Newsletter. Recipients were encouraged to forward the survey to others in their organizations to allow us to get the broadest possible range of views. The survey officially closed November 15, 2014; however, some late submissions (as of November 25, 2014) have been included.

A total of 127 responses were received but only 88 respondents answered all of the questions. Consultants and academics formed the majority of self-identified respondents; approximately 41% of the 88 respondents had more than 15 years combined education and experience.

When offered the opportunity to allocate $100 for a variety of purposes respondents said they'd focus funding on:

- Monitoring and research
- In-situ and mining operations
- Tailings, reclamation and surface water research

Respondents were asked to identify up to five (5) priority research projects they would like to see funded. A total of 277 research project ideas were submitted. Frequently cited research subjects include:

- Greenhouse gas emissions, impacts and management
- Fish, wildlife and biodiversity
- Cumulative effects characterization and management
- Reclamation certification criteria and oil sands process-affected water release criteria
- Reclamation methods
- Tailings treatment
- Water and groundwater impacts (especially chemistry)
- Wetland impacts and reclamation

A significant majority of respondents said they would focus on large field trials or pilots rather than smaller field trials or lab/greenhouse work. Respondents felt that impact assessment and impact mitigation *are currently* the primary area of research focus, while the majority felt it *should be* mitigation followed by avoidance.

Industry was selected most often as the preferred research funder, while Academic Institutions were selected as the preferred research performer. The two levels of government were seen as second choices for both funding and performing research.

Respondents were asked to identify up to five (5) priority information / data needs they would like to see filled. A total of 199 needs ideas were submitted, however there is some overlap with the research needs list. Frequently cited information priorities include:

- Open, accessible monitoring data portals
- GIS-based information
- Baseline and inventory data, especially for fish, wildlife, water quality and wetlands
- More knowledge synthesis
- More information on the impacts of oil sands development

Respondents said they look for information online first and indicated that some information is easier to find than others. It is clear that Peer-reviewed Journals are seen as the best information source – easiest to find, most frequently used and cited. Government Publications, Proceedings and Government Websites scored well in terms of being used for information. Almost 40% of respondents use Monitoring Data for information but only 7% said the data were easy to find. Data synthesis/presentation tools were identified as requiring additional development effort.

The extensive lists of research priorities and information needs provided by the respondents shows there is a clear need for ongoing work to support oil sands environmental management.

The survey responses demonstrated the need to better communicate availability of existing information and to continue to make efforts to provide easy, timely and transparent access to monitoring and research information.

It is also evident that respondents are looking for this information online, however they often find the information difficult to access. Significant effort is required, especially in government organizations, to ensure that site and document links remain permanent rather than constantly changing.

Finally, it appears that there is value in pursuing mechanisms to provide practitioners with ongoing educational and professional development opportunities.

A survey of research and information needs should be repeated periodically to track key issues and performance in addressing them. Although we made considerable efforts to get input from a broad range of parties the survey would have benefited from more participation, especially from the Aboriginal community, monitoring agencies and government (especially the federal government).

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8 ACRONYMS USED IN THIS REPORT

ABMI	Alberta Biodiversity Monitoring Institute
AEF	Acid Extractable Fraction
AEMERA	Alberta Environmental Monitoring, Evaluation and Reporting Agency
AENV	Alberta Environment (now Alberta Environment and Sustainable Resource Development)
AESRD	Alberta Environment and Sustainable Resource Development
AIEES	Alberta Innovates – Energy and Environment Solutions
AITF	Alberta Innovates – Technology Futures
ANGEL	Airborne Natural Gas Emission Lidar
ANPP	Aboveground Net Primary Productivity
AOP	Advanced Oxidation Processes
AOSERP	Alberta Oil Sands Environmental Research Program
AOSR	Athabasca Oil Sands Region
AOSTRA	Alberta Oil Sands Technology and Research Authority
BTEX	Benzene, Toluene, Ethylbenzene and Xylene
CBTAP	Clean Bitumen Technology Action Plan

CEAA	*Canadian Environmental Assessment Act*
CEMA	Cumulative Environmental Management Association
CEO	Chief Executive Officer
CEOS	Centre for Earth Observation Sciences
CEPA	*Canadian Environmental Protection Act*
CFO	Chief Financial Officer
CFS	Canadian Forest Service
CLPP	Community Level Physiological Profiling
CONRAD	Canadian Oil Sands Network for Research and Development
COSIA	Canada's Oil Sands Innovation Alliance
CRA	Commercial, Recreational or Aboriginal (fishery)
CRI	Climate Response Index
CS	Correlation Spectroscopy
CTA	Cellulose Triacetate
CVM	Coal Valley Mine
DFR	Designated Financial Representative
DIAL	Differential Absorption LIDAR
DNA	Deoxyribonucleic Acid
DOAS	Differential Optical Absorption Spectroscopy
DOE	Design-of-Experiment
DRI	Decomposition Response Index
DST	Decision Support Tool
EEF	Environmental and Economic Footprint
EIA	Environmental Impact Assessment
ELC	Equivalent Land Capability
EPEA	*Environmental Protection and Enhancement Act*
EPL	End Pit Lake
ESI	Electrospray Ionization
FID	Flame Ionization Detection

FO	Forward Osmosis
FORWARD	Forest Watershed and Riparian Disturbance
FPD	Flame Photometric Detection
FT-ICR MS	Fourier Transform Ion Cyclotron Resonance Mass Spectrometry
FTIR	Fourier Transform Infrared Spectroscopy
FY	Fiscal Year
GAAP	Generally Accepted Accounting Principles
GC-MS	Gas Chromatography-Mass Spectrometry
GHG	Greenhouse Gas
GIS	Geographic Information System
HHRA	Human Health Risk Assessment
HPLC	High Pressure Liquid Chromatography
HRMS	High Resolution Mass Spectrometry
HSI	Habitat Suitability Index
ICT	Information and Computing Technologies
IFRS	International Financial Reporting Standards
iGEM	International Genetically Engineered Machines
IMSS	Image Multi-Spectral Sensing
LAI	Leaf Area Index
LCCS	Land Capability Classification System
LFH	Luvic-Fulvic-Humic (or Litter-Fibric-Humic)
LiDAR	Light Detection and Ranging
LOC	Lab-on-a-Chip
MBCA	*Migratory Birds Convention Act*
MBI	Methylene Blue Index
MFSP	Mine Financial Security Program
MFT	Mature Fine Tailings
MICP	Microbial-induced Calcite Precipitation
MOPRA	Monitoring Procedure for Reclamation in Alberta

MS	Mass Spectrometry / Spectrometer
NA	Naphthenic Acid(s)
NARCOSS	NAIT Applied Research Center for Oil Sands Sustainability
NF	Nanofiltration
NGO	Non-Governmental Organization
OP-FTIR	Open Path Fourier Transform Infrared Spectroscopy
OSD	Oil Sands Student Delegation
OSLI	Oil Sands Leadership Initiative
OSPW	Oil Sands Process-affected Water
OSRIN	Oil Sands Research and Information Network
PAH	Polycyclic Aromatic Hydrocarbon
PAS	Photoacoustic Absorption Spectroscopy
PAW	Process-Affected Water (see OSPW)
PDMS	Polydimethylsiloxane
PFPD	Pulsed Flame Photometric Detection
PID	Photo Ionization Detection
PM	Photocatalytic Membrane
PRS	Plant Root Simulator
PTAC	Petroleum Technology Alliance Canada
PTR-MS	Proton-Transfer-Reaction Mass Spectrometry
QERT	Qualifying Environmental Trust
RAMP	Regional Aquatics Monitoring Program
RO	Reverse Osmosis
RPM	Radial Plume Mapping
RWG	Reclamation Working Group (CEMA)
SAGD	Steam Assisted Gravity Drainage
SCD	Sulphur Chemiluminescence Detection
SEE	School of Energy and the Environment
SFS	Synchronous Fluorescence Spectroscopy

SME	Small and Medium Enterprises
SNR	Signal to Noise Ratio
SOF	Solar Occultation Flux
SOP	Standard Operating Procedure
SPE	Solid Phase Extraction
STSM	State-and-Transition Simulation Model
SWAT	Soil and Water Assessment Tool
TACA	Tree and Climate Assessment
TDI	Transpiration Deficit Index
TDLAS	Tunable Diode Laser Absorption Spectroscopy
TDS	Total Dissolved Solids
UV	Ultraviolet
VOC	Volatile Organic Carbon
WBEA	Wood Buffalo Environmental Association
WSN	Wireless Sensor Network
WMS	Wavelength Modulation Spectroscopy

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