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Date of Registration - Date d'enregistrement : **November 6, 2006**

Registration No. - Numéro d'enregistrement : **1042631**

First Publication - Première publication : **Unpublished**

Title - Titre : **Proposed Criteria and Indicators of ecosystem function for reclaimed oils sands sites**

Category - Catégorie : **Literary**

Owner(s) - Titulaire(s) :
Cumulative Environmental Management Association
Suite 214, 9914 Morrison Street
Fort McMurray, Alberta
Canada, T9H 4A4

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Date of Issuance of Certificate - Date d'émission du certificat : **November 6, 2006**

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Final Report

Proposed Criteria and Indicators of ecosystem function for reclaimed oils sands sites

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Final report in partial fulfillment of
Contract No. CEMA 2005-0043

May 2006

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Part I. Introduction

The concept of Criteria and Indicators (C&I)

For the forest industry, the necessity for demonstrating responsible management practices has been recognized for over two decades. The core concept is sustainable forest management (SFM), which refers to stewardship and use of forests and forest land such that biodiversity, productivity, regeneration capacity and vitality are maintained in perpetuity. A particular challenge to SFM is the development of a methodology for demonstrating sustainability, and identifying problems in a timely fashion so that remedial actions can be employed. This methodology is built around the concept of criteria and indicators (C&I) of SFM. In essence, criteria represent the overall goals and objectives of a management program; indicators are the means for assessing how well those goals are achieved (a more detailed definition of these concepts within a mining context is provided below). C&I were first introduced at the international level in 1992, at the Earth Summit in Rio de Janeiro. In 1995, the Canadian Council of Forest Ministers (CCFM) released a national-level framework of C&I by which sustainability was defined using 6 Criteria and 83 Indicators. A variety of certification standards for SFM have since arisen in Canada and elsewhere[1] that are intended to be applied at a more local level (provincially and at the industry-level). These also require the implementation of C&I.

A critical feature of forestry-based C&I is the implicit assumption that most (if not all) of the basic ecosystem functions and services are in place at the time management

[1] These standards are listed here because there are parallels between the process and difficulties of achieving forest certification and that of mine reclamation certification. Examples are, the Forest Stewardship Council (FSC), the Canadian Standards Association (CSA), the Swedish and Norwegian-based PEFC, Sustainable Forestry Initiative (SFI), the African-based Strategic Environmental Focus (SEF) and the International Organization for Standardization (ISO 14001). These initiatives have tended to adopt C&I from government bodies. The CSA, for example, is based on the six criteria and 17 elements from the CCFM, while the SFI applies nine principals from the Sustainable Forestry Initiative Standard.

activities are implemented. This makes it possible to quantify these functions and services, at least in principle, and derive appropriate standards and thresholds. Thresholds represent the boundary or range of conditions that define sustainability limits for the resource in question. They are used to determine when deviations are large enough to warrant management intervention. Sustainability evaluations then are based upon deviations from a given standard or threshold.

This approach has its difficulties, not the least of which is the fact that many indicators show considerable inherent temporal and spatial variability, making it difficult to apply sampling programs with a resolution sufficient to detect meaningful change (Rempel et al. 2004). One approach to this problem is to use ecosystem models to project temporal and spatial patterns in selected indicators and to derive the thresholds for a given indicator (Kimmins et al.2006; see below). Sampling programs are developed that take account of these spatial and temporal trends. An application of this approach can be found in Seely and Welham (2006).

C&I within the context of Oil Sands mining

Application of the C&I approach to open-pit mining involves a very different kind of problem[2]. As a consequence of mining activities, the basic attributes of an ecosystem

[2] In Canada, terminology associated with the use of indicators (and associated criteria, and measures) has been developed to a large degree as a means of assessing sustainable forest management practices. We define, criteria, indicators, measures and values in terms more applicable to Oil Sands reclamation, as follows:

Criterion: a category of conditions or processes by which the success of a given set of reclamation practices is assessed; a criterion is characterized by a set of related indicators that are monitored periodically to assess change (Montreal Process 1995).

(structure, function, complexity, and interconnectedness) have been largely removed. Hence, from a reclamation perspective, management goals are not oriented towards maintaining some condition; rather, the objective is to restore ecosystem processes and services to a level similar to undisturbed ecosystems, within a reasonable time scale (further details below).

There is a tendency in reclamation to focus on one or a very few indicators of vegetation performance (height growth and/or site index, for example) as the predominant index of reclamation success (Young 2000). If, however, the goal of reclamation is to create an ecosystem that is self-supporting and resilient to perturbation (OSVRC 1998), a few simple measures of performance are not sufficient as a benchmark of success (Welham 2004). Vegetation structure, species diversity, and ecosystem processes, for example, have all been identified as essential components for the long-term persistence of an ecosystem (Elmqvist et al. 2003). Vegetation structure provides information on ecosystem productivity and habitat suitability, and can be useful in predicting successional pathways (Wang et al. 2004). Species diversity provides information on susceptibility to invasion by native and exotic species, and the trophic structures necessary for ecosystem resilience (Nichols and Nichols 2003, Welham 2004). Measures of ecosystem processes provide information on the biogeochemical and nutrient cycles necessary for the long-term stability and productivity of an ecosystem. The complexity of ecosystem function demands that reclamation success be evaluated in

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Indicator: a 'second order' criterion, one that adds meaning and operationality to a criterion without itself being a direct measure of performance; an indicator represents the point at which the information provided by measures (see below) can be integrated and where an interpretable assessment is possible (CIFOR 1999)

Measure: a qualitative or quantitative aspect of an indicator; a variable which can be measured (quantified) or described (qualitatively) and which when observed periodically, demonstrates trends in an indicator (Montreal Process 1995).

an integrative way using indicators that reflect vegetation structure, species diversity, and ecosystem processes. Indicators then represent the measures associated with ecosystem function that are used to assess progress towards the goal of creating a self-sustaining ecosystem. Finally, identifying plant and soil properties that integrate important ecosystem processes provides an important link between theoretical concepts of ecosystem function and operational evaluations at the local scale where most reclamation decisions and practices occur.

This report describes a comprehensive, meaningful and cost-effective list of indicators of forest ecosystem function, including a description of how they might be used to assess reclamation success. The indicators were compiled from a workshop conducted in December 2005, at the University of British Columbia. Six individuals were in attendance, Dr. Scott Cheng (U of Alberta), Mr. Dave Downing (Timberline, Edmonton), Prof. Hamish Kimmins (UBC), Ms. Nicole Robinson (consultant, Vancouver), and Dr. Suzanne Visser (U of Calgary). The workshop was facilitated by Dr. Clive Welham (FORRx Consulting). Workshop attendees were selected to provide diversity in research backgrounds, and because they had experience in Oil Sands mining reclamation and/or development of Criteria and Indicator programs. The report begins with a table (Table 1) summarizing three Criteria and nineteen indicators that were derived from the workshop. This table is designed as the main reference source for those interested in establishing a monitoring program. Detailed information on each indicator is contained within a series of appendices to the report.

Part II. Summary of indicators

The original proposal requested two lists of five to ten best Indicators of Ecosystem Functioning. The first was a list of indicators unconstrained by issues of operational feasibility, cost or complexity. The second was a list of indicators constrained according to the following conditions:

1) Operational ease: reclaimed sites are large and may be spatially heterogeneous with respect to soil conditions, moisture conditions and vegetative development. There is a need for the data/sample collection to be simple, yet credible, and appropriately account for the observed heterogeneity of the site.

2) Sampling clarity: The spatial and temporal nature of the data/sample acquisition must be clearly articulated and strengths and limitations of proposed sampling methods discussed. Where characteristics about the collected data/sample would indicate requirements for increased sampling intensity or alternative sampling locations (i.e. to maintain levels of confidence in the data/samples collected) this understanding would need to be clearly articulated such that 'subjectivity' is eliminated. For selected Indicators, appropriate sampling protocols must also be provided.

3) Costs: While it is understood that the sample/data collection and potential subsequent laboratory analysis of any indicator will incur some cost, it is critical to ensure that the cost of the indicator data be in line with the indicator's value in supporting the claim that ecosystem functioning has been re-established. Indicators that demand costly field sampling due to high requisite sampling intensity (spatial and/or temporal) and/or conducted only with specialized costly equipment and/or where subsequent

sample analysis is very costly, will reduce the likelihood of that indicator being adopted. Robust indicators that are economically inexpensive should be favored.

The efficacy of producing the two lists engendered considerable discussion among the workshop participants. In many C&I programs, the list of indicators deemed necessary for a reasonable description of ecosystem function is extensive. For example, Hickey and Innes (2005a) reviewed a total of 3000 potential indicators for British Columbia forests from 36 sources. This list of indicators was extensive, in part, because they refer to the three 'pillars' associated with forest resource management: economic, social and environmental values. The vast majority of these indicators are clearly not directly applicable to Oil Sands reclamation because they include Criteria beyond the purview of the Soil and Vegetation SubGroup (SVSG). Nevertheless, the list of potentially relevant indicators is still substantial. McHugh et al. (2005), for example, report on 27 potential indicators of ecosystem productivity relevant to British Columbia forests and these were chosen from a substantially longer list. There was a strong consensus therefore that given the highly restricted number of indicators mandated in the terms of the contract, it was prudent to focus efforts on deriving a longer list of constrained indicators at the expense of the unconstrained set.

The summary table contains 16 constrained and 3 unconstrained indicators (shaded rows in Table 1). These are grouped under 3 criteria:

C1: The physical, chemical and biological properties of the soil are restored to target levels.

C2: The structure, composition and vigor of vegetation cover are restored to target levels

C3: Critical ecosystem processes are restored to target levels

These criteria were selected because they reflect the core attributes necessary for assessing development of a reclaimed ecosystem. For each criterion, satisfactory restoration is achieved when ecosystem development (as reflected in their associated indicators) reaches target levels. It should be noted that this does necessarily mean that those levels must be equivalent to values measured or observed in mature natural stands. Rather, target levels can be set to match trajectories expected if reclaimed ecosystems are developing at ‘reasonable’ rates. These rates could be established by empirical data but for practical reasons it is more likely they will be derived in conjunction with ecosystem models (see Part III for further discussion).

Table 1: Criteria and Indicators of Ecosystem Function for reclaimed oils sands sites

C1: The physical, chemical and biological properties of the soil are restored to target** levels				
Indicator	**Rationale**	**Approach/Measurement**	**Monitoring**	**Issues**
Soil erosion	Indicates current site treatments are failing to control or exacerbating loss of soil nutrients & OM from reclaimed area. Site instability inhibits re-establishment of ecosystem functions that operate on normally stable boreal sites.	Field based measurements of: ◊ plant cover, litter cover, soil creep and erosion correlated with observed presence/absence of accelerated erosion or ◊ compared to benchmark	1-5 year intervals	Erosion is irregularly distributed in time and space, and selection of representative sites is a subjective process
Soil drainage	Can significantly impact nutrient cycling, soil water availability, and soil development.	Field assessments of drainage conditions	Annually	
Salinity	Reclamation success significantly affected by degree to which growth media or groundwater seepage waters are influenced by salinity which seriously limits plant germination and growth. Some areas may be too saline to support desired native boreal upland and non-saline wetland communities.	Field samples and laboratory analyses of conductivity, exchangeable sodium and alkalinity	Every 3 to five years initially to assess rate of change; possibly more frequently if there are marked differences in annual precipitation to determine the possible short-term effects of precipitation-induced leaching and surface flow.	A database that facilitates tracking change through time on different treatment types is needed – materials are bound to change (e.g. CT technology will probably advance). However, it is likely that present-day CT deposits will need continued monitoring for some time to assess changes in groundwater seepage quantity and quality.
Soil microbial	Plays important role in the immobilization of nutrients such as N and P. Retention of nutrients is critical to soil fertility and ecosystem sustainability, especially in nutrient-deficient soils. Soil microorganisms respond rapidly to changes in soil properties - good	Field sampling and laboratory analyses. An appropriate reference site is essential for monitoring microbial diversity in reclamation sites to determine when reclamation soil is	1st yr after site establishment, every 3-5 years thereafter	Access to respirometer or carbon analyzer is necessary otherwise costly and labour intensive. Difficult to link microbial community structure measurements (richness, abundance) with functional attributes

C1: The physical, chemical and biological properties of the soil are restored to target** levels				
Indicator	**Rationale**	**Approach/Measurement**	**Monitoring**	**Issues**
	indicators of soil quality.	approaching that in undisturbed soil.		
N-fixing symbionts	Excellent candidates for mine site reclamation because nitrogen-fixing abilities allow tolerance of inhospitable conditions while improving soil fertility and OM status (but high spatial and temporal variability early)	Field sampling and Lab analyses - Laboratory baiting studies relatively easy to conduct and provide valuable information on quality & quantity of *Rhizobium* or *Frankia* inoculum in soil.	- Detailed pre-planting assessment. - Annually for 3 years, every 3-5 yrs thereafter.	Does not require a high level of expertise.
Soil fauna	Good indicators of ecosystem function because of roles in decomp & nutrient cycling - have been shown to accelerate litter decomp, and increase rates of nutrient mineralization. Can have high reproductive potential and short generation times - respond rapidly to changes in soil structure due to reclamation activities.	Relatively easy to extract from soil and identify to suborder level; great deal of expertise required to identify to genus/species level. Requires extractor, stereo- & light microscopes. Understanding of mesofauna communities in undisturbed sites is critical to evaluating mesofauna diversity status in soils at various stages of reclamation as determined by statistical methods.	First year following establishment of reclaimed site. Every 3-5 years thereafter.	High intensity of sampling required due to high spatial and temporal variability. May be expensive due to requirement for labor with expertise in mesofauna identification - important if large numbers of samples require processing. High spatial variability may necessitate preliminary assessment in reference site to determine sampling intensity.
FF turnover/development	Reclamation success is dependent on establishment of a self-sustaining plant community. FF is an indicator of forest stability, since FF development (i.e. OM accumulation) tends to stabilize as forest community stabilizes. FF represents a nutrient and microbial (mycorrhizal, N-fixing) pool that is critical to a self-sustaining plant cover and provides matrix for biological activity and healthy root growth.	Field Measurements – samples of LFH and OM accumulation as carbon Lab analyses - dried forest floor material or separated LFH layers.	First year and every 3-5 years	High spatial & temporal variability during the early stages of ecosystem development, but should decrease with time as forest stabilizes and carbon inputs (litterfall) and outputs (respiration) stabilize.
Litter quality	Controls of litter quality on soil nutrient	Field sampling and lab analyses –	Annually within first 5	Research specific to plant species

C1: The physical, chemical and biological properties of the soil are restored to target** levels				
Indicator	**Rationale**	**Approach/Measurement**	**Monitoring**	**Issues**
	(N in particular) cycling and availability play a major role in sustainability of ecosystems being established on the reclaimed sites. Litter quality affects rate of litter decomposition, soil organic matter build-up, soil nutrient dynamics, and ultimately soil/site condition.	Litter traps and/or Direct litter sample collection off the forest floor surface operationally feasible to collect and sampling clarity is good as long as well designed protocol is followed.	years of reclamation and then can be reduced	and sites in the oil sands is required in order to apply this indicator to effectively monitor the effectiveness of reclamation success.
Soil nutrients	Soil nutrient concentrations or contents are potentially the most direct measure of potential nutrient availabilities in the soil for plant primary production.	One of the most useful measures of the soil nutrient indicator would be the net N mineralization rate, which has been found to be closely related to primary productivity. Soil samples and lab analyses	Spatial variability of soil nutrient measures expected to be very large due to large variability of soil; would require lg # of samples to be collected from plots set up to monitor progress of reclamation. Best approach: perform preliminary investigation to find site variability & perform statistical analysis to determine min # samples to achieve the desired power of stat test. Every 5 years	Dynamics mean that soil nutrient concentrations measured at any one time likely a poor predictor of plant growth; so, when & how often to measure complex issues. Also - lack of clarity in methods involved in measuring soil nutrient availability (timing in the growing season and in rotation of forest stand, and lack of consistent or reliable extraction methods). Cost for achieving high reliability can be very high.
Mycorrhizae	Mycorrhizal fungi essential to establishment, growth and reproduction of higher plants, especially in nutrient-poor soils such as those characteristic of the boreal forest. MF increase plant nutrient supply leading to greater yield and nutrient	Conduct a detailed baseline survey of ectomycorrhizal and arbuscular mycorrhizal potentials in reclamation soil and a comparable reference soil prior to planting to establish the presence and identity of mycorrhizal inoculum	Detailed initial survey; annually for first 3 years after plant establishment; every 3-5 yrs thereafter	Due to time-consuming nature of both field and laboratory assessments, # of samples and amount of soil investigated for mycorrhizal status usually very low, relative to area of site. Regardless of the methodology,

C1: The physical, chemical and biological properties of the soil are restored to target** levels				
Indicator	**Rationale**	**Approach/Measurement**	**Monitoring**	**Issues**
	accumulation in vegetation.	Soil samples (coring) and laboratory baiting method to determine mycorrhizal development.		measurements of mycorrhizal diversity are costly, requiring great deal of time and expertise.

C2: The structure, composition and vigor of vegetation cover are restored to target** levels				
Indicator	**Rationale**	**Approach/Measurement**	**Monitoring**	**Issues**
CWD	CWD plays significant role in wildlife habitat, long-term humus supplies and slope hydrology, and, in some ecosystems, in regeneration processes (a seedbed elevated above competing vegetation and the influence of seed pathogens).	Document range of variation in CWD in pre-mining stands, and then forecast temporal patterns of CWD that could be expected to develop over time in the reclaimed land using an ecosystem management model.	Comparison of predicted to observed as ecosystem develops (temporal fingerprint).	Because it will take centuries for CWD to accumulate to significant levels in reclaimed stands, this is not a useful measure of early ecosystem recovery. This indicator constrained by time it will take for stand development processes to produce CWD.
Snags	Snags provide important habitat for a variety of vertebrate species; wood-boring insects. When they fall, contribute to inventory of CWD. Not essential for ecosystem primary productivity, but are required if forest is to support the full diversity of native organisms.	Inventorying snags - relatively easy and inexpensive. Ecosystem models should be used to predict anticipated production of snags in stands on reclaimed mined land. Temporal variability should be addressed through modeling. Spatial variability should be documented in mature pre-mining stands to establish characteristic spatial patterns of mortality, by ecosystem type.	Comparison of predicted to observed as ecosystem develops (temporal fingerprint).	This indicator constrained by time it will take for stand development processes to produce snags.
Plant species diversity	Re-establishment of natural biodiversity	Field sampling	Every five years for the	

index	by reclaiming post-mining landscapes to communities - similar to native communities in composition and structure.		first 20 years; thereafter, every 10 years.	
Invasive species	"Invasive plant species" could be indicator of reclamation success if native species successfully invade post-mine sites and re-establish ecological function. Could also be considered an indication of reclamation failure if weedy or exotic species take over and prevent succession to native communities and/or create further problems on-site or off-site (e.g. escaping into stream drainages and spreading along major rivers).	*Ocular assessments of species composition and cover in plots.* Documentation (population estimates, digital photographs, GPS locations) for undesirable plants and particularly for noxious, restricted or nuisance weeds.	Every five years for the first 20 years; thereafter, every 10 years. (native species) Continuous monitoring (restricted, noxious, or nuisance weeds and exotic species that may be considered problem plants.)	Targets vary by category: *Desirable native invaders*: occurrence and abundance similar to target natural plant community *Restricted, noxious or nuisance weeds:* Target is no occurrence. *Exotic species:* Target depends on reclamation objective; eventual target is no occurrence for those species that might be come problems (e.g. smooth brome, crested wheatgrass
Wetland input water chemistry	Input chemistry reflects the health of nearby upland ecosystems.	Standard field and laboratory test methods for water sampling.	5 year intervals	Temporal changes in process water inputs,
Foliar nutrition	Foliar nutrient concentration directly related to health of plant species. N and P – most important nutrients (most likely limiting) but others as well depending on mineralogy, degree of soil development, mycorrhizal associations, competition, climate, and soil physical, chemical & biological conditions. FN thus provides indication of overall growth condition as mediated by range of factors (above), and could be an effective indicator of ecosystem functioning.	Foliar samples are operationally feasible to collect and sampling clarity is good as long as a very well designed protocol is followed. Standard sampling protocols call for collecting foliar samples from upper 1/3 of crown, and collecting fully expanded, sun-lit leaves in dormant or least physiological active season.	Annually within first 5 years and then can be reduced	Foliar nutrient concentration or some of the other proposed measures alone do not provide an adequate indication of forest stand nutrient limitations partly because nutrients are recycled in a forest stand quite efficiently and dependence of trees on soil nutrient supply can be weak.

C3: Critical ecosystem processes are restored to target** levels				
Indicator	**Rationale**	**Approach/Measurement**	**Monitoring**	**Issues**
Nutrient budget	Combination of the nutrient inventory in inactive forms plus a measure of quantity and rate of nutrients participating in the active cycle is a fundamental indicator of the potential net primary production (NPP) and resilience of the ecosystem.	• Nutrient analysis of soil samples • Monitoring plant biomass accumulation and tissue nutrient concentrations to establish nutrient inventories in live vegetation • Monitoring nutrient returns in above-ground litter	Field sampling and lab analyses at 10 year intervals. Establishment of benchmark values pre-mining.	High temporal variability – ecosystem simulation model may be used to track expected vs. actual nutritional status.
Ecosystem NPP	Re-establishment of net primary production (NPP) of the ecosystem involving the appropriate plant species and stand structure (and, therefore, wildlife habitat and various measures of biological diversity) is the ultimate objective of reclamation.	Complexity of issue suggests use of ecosystem models designed to simulate NPP of both tree and non-tree plant species. These models must explicitly address major determinants of production ecology – nutrients, moisture and climatic control of net photosynthesis and carbon allocation. Data collection for ecosystem NPP involves the set of calibration data for ecosystem management model selected for purpose.	Comparison of predicted to observed as ecosystem develops (temporal fingerprint).	Empirical assessment of ecosystem NPP is constrained by cost - can be avoided by calibrating & validating an appropriate ecosystem management model, which then becomes the forecaster of expected ecosystem NPP under various disturbance scenarios. These “temporal fingerprints” of ecosystem NPP become benchmark against which to assess recovery of reclaimed ecosystems.
Plant carbon allocation	Carbon allocation to, and turnover of, fine roots - good indicator of condition of soil relative to tree and plant demands. If ecosystem disturbance reduces site inventory of available nutrients, and/or the availability of soil moisture, variation in measurable above-ground growth may reflect carbon allocation shifts as much or more than variation in NPP. The allocation of energy (and carbon) to fine roots, and the longevity and turnover of these fine roots, are a major component	Carbon allocation will vary according to the availability of nutrients, moisture and light. The best way to address this is to prepare temporal fingerprints of variation in carbon allocation using a suitable ecosystem model, and then sample at intervals suggested by the model to check whether ecosystem is tracking the expected temporal pattern.	Comparison of predicted to observed as ecosystem develops (temporal fingerprint).	Monitoring carbon allocation, especially to fine roots, is constrained by technical difficulties and cost. It is recommended that a limited research project be undertaken to define the variation in below ground allocation between un-mined sites that vary in site fertility, and that these data be used as a benchmark for limited studies of carbon allocation over a chronosequence of plantations on reclaimed mined

	of carbon allocation. This is especially so on nutrient deficient soils.			land.

Part III. How to implement a monitoring program using Criteria and Indicators

Setting objectives

Monitoring involves the acquisition of data or information for comparison to an explicit standard of performance (McClain, 1998). As such, it can be used to determine whether through space and time, operational strategies and practices are consistent with overall goals and objectives. Once a suite of indicators has been selected, one objective of the monitoring program is to ‘calibrate’ a given indicator with data derived from reference sites (Hobbs and Norton, 1996). These reference sites provide benchmark values for a given indicator, and thus they need to be selected carefully. **Reference sites should be equivalent ecologically to their reclaimed analogue and located close to the restoration project so that climatic regimes and other natural disturbances are similar** (SER, 2004). Details regarding plot layout and sampling intensity are beyond the purview of this document and will not be discussed in detail (see also below).

Evaluating a given indicator may be a simple matter of obtaining an estimate from a reclaimed site and comparing its value to the appropriate benchmark. Soil drainage and foliar nutrition are examples of these *static* measures (Table 1). As noted above, however, a critical distinction between reclaimed and forest ecosystems is that in the former, there may not be a prior measurement for a given indicator that can be linked meaningfully to a natural benchmark. In this case, the objective is to restore a given indicator to a level characteristic of the reference ecosystem. **Success can be evaluated by the rate at which a given indicator is returning to a reference level.** These involve *dynamic* measures associated with a given indicator. General protocols for establishing dynamic measures are discussed below.

Finally, an important benchmark of reclamation success is the achievement of equivalent capability (EQ)[3]. **As an overall objective of reclamation, EQ might be realized when a defined suite of indicators for a reclaimed site has achieved values that lie within the natural range of variation measured on a natural analogue and/or match temporal trends in values derived from simulation models.**

Sampling for static and dynamic indicators

From the perspective of monitoring, the issue of cost-effectiveness (the fourth attribute of a good indicator) is more than simply the price required to obtain a given sample. Cost-effectiveness also refers to the number of samples required to document conclusively (in a statistical sense) whether the level of a given indicator, or its rate, is outside threshold boundaries. Hence, the cost of monitoring a particular indicator is meaningless unless consideration is given to its inherent variability, how much change in the indicator is required before thresholds boundaries are violated, and how much statistical power[4] is considered acceptable for a meaningful comparison with threshold values. See Seely and Welham (2006) for an explicit example of this approach.

[3] Equivalent capability (definition): the ability of the land to support various land uses after conservation and reclamation is similar to the ability that existed prior to an activity being conducted on the land, but that the individual land uses will not necessarily be identical (OSVRC 1998)

[4] Statistical power is the probability you will detect a meaningful difference, if one exists. Ideally, studies should have power levels of 0.80 or higher -- an 80% chance or greater of finding a difference if one was really there. The "power" of any individual study depends on (1) the number of samples (sample size), (2) the expected size of the effect one is looking for; and (3) the precision of the measurements. All else being equal, statistical power increases with increasing sample size, larger expected effects, and more precise measures. As a general rule, larger numbers improve accuracy.

Distinguishing between indicators that possess a static threshold (whose value can be measured directly and compared immediately with the reference value) versus those with values that track towards the threshold is an important consideration in designing the sampling program. Static indicators can probably be sampled less often compared to a dynamic indicator, at least initially, because the latter requires establishing a documented pattern of change in a given direction.

With dynamic indicators, monitoring must evaluated against the patterns of change in the conditions or values of interest that would be expected if an ecosystem *is* being reclaimed successfully. These expected changes in “healthy”, “normally” functioning, post-reclamation ecosystem constitute *temporal fingerprints* of ecosystem function (this concept is developed in a forestry context by Kimmins 1990a,b, 2002) Two approaches are available for creating temporal fingerprints, field sampling and ecosystem model projections. Establishing temporal fingerprint by empirical means alone is prohibitive because it requires information from natural ecosystems that span the range in ecosystem types, ages and stages of development anticipated on reclaimed sites. Ecosystem simulation models have the advantage that established reclamation practices can be simulated explicitly, timelines for projected development matched to available empirical data, and alternative practices modeled relative easily. The difficulty with the modeling approach is the lack of data with which to validate projections definitively. **Regardless of the limitations of these approaches and given that experience alone is insufficient (at this time) as the basis for evaluating reclamation practices, a monitoring program cannot be effective without the creation of temporal fingerprints.**

Generally, sampling for dynamic indicators is conducted in two phases (see Kimmins et al. 2006). In the first phase, sampling is focused on defining the relationship between ecosystem processes and structures (as reflected in the indicators) and the ecosystem conditions/values of interest (creating a self-sustaining ecosystem with a capability equivalent to a natural analogue). In Phase I, monitoring data collection is designed to develop and calibrate these relationships both empirically and within the ecosystem modeling framework. For example, two classic measures of ecosystem performance are site index and height growth. These two measures are a consequence of among other things, the underlying soil-based processes that supply nutrients from decomposition. An objective of Phase I monitoring is to establish how these processes are linked to performance. To some degree, this is already occurring with the soil-based indicators as part of the calibration procedure for the LCCS. Phase I often appears closer to applied research than it is to conventional monitoring. It will be somewhat more expensive and demanding than the ‘routine’ monitoring employed for static indicator assessments, but this will be more than offset by the reduced on-going monitoring costs and increased effectiveness of the monitoring activity in Phase II. The data collection in Phase I serves the dual purpose of relatively standard environmental monitoring and the development and testing of the predictive models.

Once the monitoring support system has been established and verified in Phase I, Phase II begins when on-going monitoring is reduced to periodic lower-intensity, targeted data collection to provide a check on the reliability of the system, and to steadily increase the data upon which it is based. Alternative reclamation scenarios can also be considered and integrated within the monitoring program to assess their relative utility.

Next steps

For practical reasons, this contract specified the selection of a very limited set of indicators from a long list (see, for example, Hickey and Innes 1995a). Our intention was to develop the core set of indicators that were absolutely essential to ecosystem performance and the achievement of equivalent capability. Nevertheless, this list is incomplete. Indicators of vertebrate biodiversity, for example, were not included though they are often used as measures of ecosystem health (see Rempel et al. 2004, for example). Our indicator list also largely reflect outputs i.e., the result of ecosystem processes; monitoring should include inputs (climate variables). Inputs are important because they can be a major determinant of ecosystem development independent of any reclamation protocols/practices. Without these inputs it will be impossible to determine whether ecosystem development is a consequence of reclamation practices (as reflected by the indicators), or is climate driven.

How can a comprehensive and effective indicator and monitoring program be implemented? First, the SVSG should provide funding to develop a more comprehensive list of potential indicators. The list provided here is a necessary start. It was conceived and developed with an emphasis on constrained indicators because these were the most practical to implement. Even if all of the indicators (constrained and unconstrained) are adopted, it is unlikely the monitoring program will capture the full range of ecosystem function and services of interest to stakeholders. One of our indicators, for example, assesses overall plant biodiversity. For some stakeholders, reclamation success (and equivalent capability) might be judged simply by the abundance of particular species (berry producers or mushrooms, for example). Consideration might be given therefore to including indicators that are of specific interest. Secondly, the list provided here was derived after consultation with individuals possessing broad range of expertise. Direct stakeholder involvement was not an active part of the process. There is a risk therefore that despite its best intentions the workshop group may have put forward one or more constrained indicators that the industry does not consider cost-effective. Consultation among industry representatives (specifically the SVSG) should be actively encouraged therefore in the development of subsequent indicators, probably through one or more workshops. With some guidance, considerable progress can be made in educating industry regarding the C&I program and developing useful indicators. One of us (Nicole Robinson) has participated in this process, while Hickey and Innes (2005a) discuss the outcome of a similar exercise.

Finally, to realize its full value a C&I program should be integrated within, and used to inform, existing decision support frameworks. As noted above, the LCCS depends upon establishing relationships among various soil-based indicators and ecosystem productivity measures (principally site index). While this is useful and informative, it is largely a static exercise because it does not effectively capture the temporal fingerprint. If properly implemented, the C&I program should be capable of addressing this issue. Hence, its results can provide a complement to the LCCS. The revegetion manual provides a series of prescriptions as to which vegetation is the most appropriate for a given set of features associated with landscape position and cover type. A major shortcoming of this tool in its present form is that it provides no guidance as to how a given prescription can be evaluated with respect to its utility in achieving a desired outcome. Hence, a revised edition of the revegetation manual should include a detailed description of those indicators that are relevant to evaluating ecosystem composition and vegetation performance.

General considerations

Communication within stakeholder groups. Implementing and maintaining a monitoring program can be a complex and potentially expensive proposition, even if it involves only a relatively small list of indicators. Under these circumstances, there is a significant risk that it will not be done properly; neither the regulatory agencies nor industry will have the budget or human resources to collect vast amounts of data. Committing the resources necessary to properly analyze and interpret the data also poses a serious obstacle because it limits the feedback from monitoring to reclamation policy and practice. Both issues can be avoided if proposed indicators are closely matched to reclamation objectives, the utility and application of each indicator is clearly defined and understood by all participants, and the program uses a phased approach as described above. Effective communication of these concepts is essential simply because it is the practitioners who must implement the monitoring program effectively and justify its existence and cost to those who control the budget.

Communication among stakeholder groups. Monitoring programs have been established throughout the Oil Sands region by each of the groups responsible for the various aspects of mining impacts and reclamation. Furthermore, these programs operate at a myriad of spatial scales. Regardless of whether the monitoring program implemented by the SVSG (or any group within the Oil Sands region) is developed within the context of C&I, conflict will inevitably develop among these groups as to how a given set of monitoring information is interpreted. For example, soil nitrate levels (a measure of Wetland input water chemistry; see Table 1) can be considered an indicator of high levels of nitrogen availability (Doran and Parker 1994). From a reclamation perspective this might be a desirable condition if it correlates with terrestrial ecosystem production (hence, more of both is better). For a wetland system, however, dissolved nitrogen encourages eutrophication and in a wetland monitoring system, high levels might be considered problematic. Hickey and Innes (2005b) refer to this conflict of values as the ‘new medievalism’. It occurs because different stakeholders have interests in multiple, overlapping sites and between them they operate at a range of scales (see also Haufler 2003). New medievalism is common to many overlapping monitoring programs.

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Appendix 1

INDICATORS OF ECOSYSTEM FUNCTION FOR RECLAIMED OIL SANDS SITES

Indicator: Nutrient budget

Scientific Rationale

The most fundamental aspect of ecosystem function is energy capture and storage in the form of organic matter. This storage is in the form of chemical bond energy. Net primary production – the key measure of ecosystem energy flow – is deterministically related to the uptake of a balance of nutrients by plants, their loss from plants as litterfall and plant mortality, and their release back to a plant-available form through the microbially-mediated process of decomposition and mineralization. Nutrient chemicals are thus the chemical "conveyor belt" that moves energy through the food web of ecosystems. The nutrient cycling aspect of the nutrient budget (a record of the flows of nutrients in various pathways) is closely related to NPP and ecosystem function. This dynamic aspect of the nutrient budget is not necessarily an equally good indicator of ecosystem resilience, however. If all the nutrients in the ecosystem are actively participating in energy flow and the biomass they are associated with is lost by fire, erosion or harvest, ecosystem productivity will decline dramatically. There is no reservoir of currently inactive nutrients from which to restore the nutrient cycle, which must therefore be rebuilt over time from small annual inputs to the ecosystem in precipitation, weathering and/or other input mechanisms, depending on the nutrient involved. If, on the other hand, there is a large reservoir of nutrients in currently inactive soil organic matter or un-weathered minerals, the nutrient cycle will rebuild as fast as this inventory becomes available and there are plants to re-establish the cycle.

The combination of the nutrient inventory in inactive forms plus a measure of the quantity and rate of nutrients participating in the active cycle is a fundamental indicator of the potential net primary production (NPP) and resilience of the ecosystem. Reclamation success in re-establishing ecosystem function should therefore be judged by the development over time of both these aspects of the nutrient budget. The rate at which the budget is built will depend on many other factors of course, including the development of microbial populations, soil aeration and drainage, soil moisture, re-establishment of vegetative cover and leaf area, and other factors that influence the processes of nutrient cycling. However, the budget integrates these many effects and is therefore a good overall indicator of ecosystem function.

Constrained/Unconstrained

Monitoring nutrient budgets is relatively straight forward and cost effective. It requires:

1. Soil sampling and nutrient analysis for organic matter, total nitrogen, mineralizable nitrogen, and any other limiting nutrient such as phosphorus and potassium. Sulphur and micronutrients can also be important. Tree nutrient status can be assessed by vector analysis and/or DRIS type analyses.
2. Monitoring plant biomass accumulation and tissue nutrient concentrations to establish nutrient inventories in the live vegetation
3. Monitoring nutrient returns in above-ground litter; below ground litterfall (fine root turnover) is addressed below under carbon allocation.

Field sampling and lab analyses for these variables are well established and not excessively expensive. A 10 year sampling interval should give a good indication of ecosystem development.

Because a trend cannot be defined by two points (this defines a straight line), at least three samples are required to indicate ecosystem development. This could be accomplished by an initial post-reclamation sample, and one at 10 and 20 years. If a prediction concerning the anticipated development of the nutrient cycle needs to be provided over a shorter period, the best approach is to calibrate an ecosystem management model that represents nutrient budgets and their relationship to NPP. Calibration data should come from pre-mining local ecosystems. Such a model can be used to establish a “temporal fingerprint” of ecosystem change for a variety of expected ecosystem development trajectories. Sampling at 5 and 10 years could then be used to compare with this temporal fingerprint to establish whether or not the ecosystem is following a desired trajectory, and what the longer term ecosystem potential is. The model output could be used to show how far the reclaimed land deviates from the ecosystem development trajectory of the pre-mining stand, how fast a deviant trajectory could be moved towards some desired trajectory through various management actions, and how long it would take in the absence of management interventions for “natural” processes to achieve this.

Nutrient availability is linked to ecosystem productivity through its deterministic relationship to leaf area, foliar nutrition and photosynthesis. Leaf area and nutrition may be easier and less costly to monitor than nutrient cycling.

Spatial and temporal variability

Nutrient cycling varies significantly over the stand development cycle. Post disturbance increases in nutrient availability (the assart period) are followed by a period of reduced availability, with a gradual recovery towards the pre-disturbance levels. The relative importance of biogeochemical, geochemical and internal cycling also varies over time. Documentation of this temporal variation requires sampling at least every decade throughout the rotation, **or** the use of an ecosystem management model to forecast the temporal fingerprint of variation, with infrequent sampling to check for consistency between predicted and observed.

The nutritional status of a forest varies spatially between different ecosystem types (site types – differences in soil moisture and fertility), in the vicinity of different tree and understory plant species, and with variation in site history. At a fine scale (a few meters) there is variation caused by individual tree effects. This variation requires random sampling with a level of replication established by a preliminary sample to establish the site-specific level of spatial variation in the parameters of interest.

Measurement and Monitoring Program

Measure	Msrmn t unit	Min/Max Values (Targets) and/or Expected Trends	Information sources *Where do you get the data?*	Methodologies to determine values (including spatial assessment)	Interpretation *What do the data show?*	Frequency of data collection	Linkages
Live plant biomass by component	t/ha	Temporal fingerprint established by ecosystem management model	**Ecosystem model, field sampling**	Ecosystem modeling, Standard field cruise of live biomass	Compare field data with temporal fingerprint from ecosystem model	Decadal, or 5yrs for initial comparison with temporal fingerprint	
Litterfall; mass and nutrient content	t/ha/yr	Temporal fingerprint established by ecosystem management model	**Ecosystem model, field sampling**	Litter traps	Compare field data with temporal fingerprint from ecosystem model	After tree canopy closure	
Tissue nutrient concentratio ns	%	From the literature and field sampling across a range of site productivities	**Literature and field sampling**	Field tissue sampling and standard analyses	Compare field data with literature values and sampling across a soil fertility and tree productivity gradient. Vector or DRISS analysis	Every 5 years until after the assart period. Then every 10 years	
Soil nutrients; total. Available	kg/ha	Temporal fingerprint established by ecosystem management model. From the literature and field sampling across a range of site productivities	**Ecosystem model, field sampling**	Standard soil sampling to 30 cm depth. Standard soil analyses	Compare field values with model predictions	At start of plantation and every 10 years	

Fine root sampling*	t/ha	Research to establish carbon allocation to fine root biomass across a gradient of soil fertility.	**Field research project**	Standard root coring	Compare with literature data	After canopy closure”	

* note that nutrient cycling in fine roots will require a measure of fine root turnover – see carbon allocation below

Indicator: Plant carbon allocation

Scientific rationale.

One of the most important aspects of ecosystem function in highly disturbed ecosystems, or in those in which nutrients have low availability to plants, is carbon allocation. Carbon allocation reflects plant “strategies” (evolved in response to competitive pressures). In light-limited environments, shade-intolerant plants allocate carbon to height growth, while shade tolerant plants may allocate to branch growth, stem diameter growth and root growth (to deal with below-ground competition). In nutrient-limited environments, allocation is preferentially towards fine roots and support of mycorrhizae in order to capture the nutrients needed to develop and sustain foliage for light gathering. Root allocation is also important in moisture-limited environments. Carbon allocation to, and turnover of, fine roots is a good indicator of the condition of the soil relative to the tree and plant demands.

The importance of carbon allocation to fine roots in determining above-ground growth, and the above-ground allocation between height and diameter growth, has been demonstrated in many species and in many countries. While there continues to be debate over the exact details of the biochemical and other aspects of carbon allocation, it is clear that if ecosystem disturbance reduces the site inventory of available nutrients, and/or the availability of soil moisture, variation in measurable above-ground growth may reflect carbon allocation shifts as much or more than variation in net primary production. The allocation of energy (and carbon) to fine roots, and the longevity and turnover of these fine roots, are a major component of carbon allocation. This is especially so on nutrient deficient soils.

Allocation to fine roots is the most difficult aspect of carbon allocation, yet is frequently the most important. The longevity and turnover of fine roots are difficult and expensive to measure. However, allocation to fine roots is a good integrative indicator. It is recommended that some limited fine root studies be conducted to establish the relationship of this aspect of ecosystem function to other variables that are being monitored. Such knowledge is important for the calibration of ecosystem management models that should be a key component of any reclamation monitoring program.

Constrained/unconstrained.

Monitoring carbon allocation, especially to fine roots, is constrained by technical difficulties and cost. It is recommended that a limited research project be undertaken to define the variation in below ground allocation between un-mined sites that vary in site fertility, and that these data be used as a benchmark for limited studies of carbon allocation over a chronosequence of plantations on reclaimed mined land. The data are also needed for the calibration of an ecosystem model. These studies should include fine root studies by soil coring (post soil thaw, spring, summer and fall samples) and root-ingrowth bags. In-situ rhizometers (root growth observation chambers) should be used to establish seasonal fine root activity, but soil coring/ingrowth bags will probably be the least technically demanding methodology. The combination of limited field measurement and data from the boreal forest literature should be used in appropriate ecosystem management models to reduce the costs of assessing carbon allocation empirically. Carbon allocation in young trees (planting stock) should be conducted in pots in greenhouse studies.

The temporal patterns of carbon allocation to other tree biomass components is traditionally done on the basis of biomass regression equations. These are generally accurate for stems, and possibly for large roots, but are notoriously poor for branches and foliage and small roots beyond the stand age range and particular sites on which they are based. The ENFOR program established biomass regressions for most of the major tree species across Canada. These could be used to establish biomass ratios in pre-mining stands. Preparation of new regressions in the developing stands on reclaimed lands will be necessary to identify total plant biomass and gross carbon allocation (excluding fine roots).

Spatial and temporal variability

Carbon allocation will vary according to the availability of nutrients, moisture and light. As these change over the life of a stand, so does carbon allocation. The best way to address this is to prepare temporal fingerprints of variation in carbon allocation using a suitable ecosystem model, and then sample at intervals suggested by the model to check on whether the ecosystem is tracking the expected temporal pattern.

Measurement and Monitoring Program

Measure	Msrmnt unit	Min/Max Values (Targets) /Expected Trends	Information sources *Where do you get the data?*	Methodologies to determine values (including spatial assessment)	Interpretation *What do the data show?*	Frequency of data collection	Link ages
Whole plant carbon allocation pre-mining	% biomass by compone nt	Max/min values established by studies on a catena of site qualities. Temporal fingerprint established by ecosystem management model	**Existing biomass regression models. Field sampling to establish local regressions or to verify existing equations, ecosystem modeling.**	Literature search. Standard field cruise of live biomass to fill data gaps in regression preparation. Destructive sampling	Variation of biomass ratios over stand age.	Pre-mining, 5yrs for initial comparison with temporal fingerprint. 15 , 30 year followup	
Fine root studies; biomass, turnover	t/ha/yr	Max/min values from field study of stands over a chronosequence. Temporal fingerprint established by ecosystem management model	**Field sampling. Literature. Ecosystem model.**	Fine root coring and ingrowth bag studies. Ecosystem modeling. Possibly some root chambers. Greenhouse pot studies of young trees. 1 yr study	Variation of fine root allocation over stand age. Establish carbon allocation to fine roots and fine root turnover across a gradient of soil fertility. Compare field data with temporal fingerprint from ecosystem model Compare with literature data	Pre-mining, 5yrs for initial comparison with temporal fingerprint. 15 , 30 year follow-up	

Indicator: Ecosystem NPP

<u>Scientific rationale</u>

Re-establishment of net primary production (NPP) of the ecosystem involving the appropriate plant species and stand structure (and, therefore, wildlife habitat and various measures of biological diversity) is the ultimate objective of reclamation. Ecosystem NPP is the sum total of tree and non-tree plant species NPP, both above and below ground. Visual NPP will be much lower than total NPP in disturbed ecosystems if this results in significant shifts in NPP below ground. Consequently, NPP requires both above and below ground assessment.

NPP on its own is not a complete description of ecosystem function. The longevity and chemical character of dead organic matter, its decomposition characteristics and the stability of final products of decomposition (humus) are also important as they relate to the resilience of the ecosystem in the face of future disturbance (logging, fire, insects).

The complexity of this issue suggests the use of ecosystem models designed to simulate NPP of both tree and non-tree plant species. These models must explicitly address the major determinants of production ecology – nutrients, moisture and climatic control of net photosynthesis and carbon allocation. Data collection for ecosystem NPP thus involves the set of calibration data for the ecosystem management model selected for the purpose.

Constrained/unconstrained

Empirical assessment of ecosystem NPP is constrained by cost. This can be avoided by calibrating and validating an appropriate ecosystem management model, which then becomes the forecaster of expected ecosystem NPP under various disturbance scenarios. These “temporal fingerprints” of ecosystem NPP become the benchmark against which to assess the recovery of reclaimed ecosystems.

Spatial and temporal variability

Ecosystem NPP will vary over time as a function of changing leaf area, which in turn reflects changes in nutrient availability and cycling. This variability is best predicted using an ecosystem model. Ecosystem NPP can be fairly uniform across a uniformly stocked stand within a particular ecosystem type. It will vary spatially with ecosystem site type, leaf area and the soil resources that determine leaf area.

Measurement and Monitoring Program

Measure	Msrmnt unit	Min/Max Values (Targets) /Expected Trends	Information sources *Where do you get the data?*	Methodologies to determine values (including spatial assessment)	Interpretation *What do the data show?*	Frequency of data collection	Link ages

Ecosystem NPP	t/ha/yr	Max/min values established by studies on a catena of site qualities. Temporal fingerprint established by ecosystem management model	**Model calibration data set: literature, growth models, file data, field studies to fill data gaps**	Model calibration, validation and gaming	Temporal fingerprints of ecosystem NPP to act as a benchmark for field monitoring	Initial model calibration. 5 year review of calibration data set to update with new data	

Indicator: Coarse woody debris

Scientific rationale

Coarse woody debris (CWD decaying logs on the ground, stumps and large roots) is an important component of most unmanaged forests. They are less important where CWD decays very rapidly, and in forests in which such ecosystem structures are removed frequently by fire, but for most unmanaged forests they play a significant role in wildlife habitat, long-term humus supplies and slope hydrology, and, in some ecosystems, in regeneration processes (a seedbed elevated above competing vegetation and the influence of seed pathogens). CWD is habitat for a variety of insects, mammals, reptiles and birds, and are thus involved in a variety of forest food chains. In intensively managed forests CWD is less abundant because tree mortality – the source of CWD – is limited due to stand thinning, although the stump and root system components of CWD created by thinning contribute to biodiversity, wildlife habitat and food chains, and to soil physical, hydrological and chemical characteristics.

It is claimed by some that the presence of CWD (generally meaning the visible, surface accumulation of decaying logs) is essential for “forest health”. This conclusion depends on the definition of “health”. In some forests, the presence of freshly downed logs can lead to bark beetle outbreaks that can cause extensive mortality of the living trees. Many healthy (from a pathological perspective) managed forests are productive and sustain this productivity over many generations in the absence of surface CWD. These forests do not sustain the full range of non-tree species that an unmanaged forest with CWD on the same site would be expected to support, but in terms of nutrient cycling and tree NPP must be considered “healthy”. Thus, the presence of CWD generally relates more to biodiversity objectives and wildlife than to any fundamental, ubiquitously-applicable measure of “ecosystem health”. Where CWD contributes significantly to hydrological function and reduction of erosion, it can be said that it contributes to the resistance and resilience stability of the ecosystem.

Because CWD is a feature of unmanaged or extensively managed forests, it is often listed as a goal of management. Because it will take centuries for CWD to accumulate to significant levels in reclaimed stands, this is not a useful measure of ecosystem recovery. The expected trajectory of CWD accumulation should be forecast using an ecosystem management model.

Constrained/unconstrained

Monitoring of CWD is easy and inexpensive. However, it cannot be done until it has been created. This indicator is thus constrained by the time it will take for stand development processes to produce it. The best that can be done is to document the range of variation in CWD in pre-mining stands, and then to forecast the temporal patterns of CWD that could be expected to develop over time in the reclaimed land using an ecosystem management model. Such a model should be used to examine what management interventions (e.g. stand thinning and some tree girdling) could be undertaken to accelerate the production of snags and CWD if this is a management objective.

Measurement and Monitoring Program

Measure	Msrmnt unit	Min/Max Values (Targets) /Expected Trends	Information sources *Where do you get the data?*	Methodologies to determine values (including spatial assessment)	Interpretation *What do the data show?*	Frequency of data collection	Link ages
CWD	t/ha by decay class and species	Max/min values established by studies on a catena of site qualities in un-mined areas. Temporal fingerprint established by ecosystem management model	**NRV established by data collection in pre-mined stands. Future trend predicted by model**	Standard line intersect sampling Model calibration and simulation	Temporal fingerprints of CWD to act as a benchmark for expected future CWD	Initial model calibration.	

Indicator: Snags.

Scientific rationale

Snags are a feature of the understory re-initiation and old growth phases of stand development. They are present in these phases of every seral stage of forest succession. Generally, standing dead trees smaller than some specific diameter are not included in the inventory of snags because they are too transitory and do not fulfill the same ecological functions as larger dead tree stems. Thus, trees dying in much of the stem exclusion phase of stand development are not included.

Snags provide important habitat for a variety of vertebrate species – mostly birds and mammals – for nesting/denning. They are also habitat for many wood-boring insects, which in turn are food for birds such as woodpeckers. When they fall, they contribute to the inventory of CWD. Snags are not essential for ecosystem primary productivity, but they are required if the forest is to support the full diversity of native animals. Relatively young (recently dead) snags that still have branches are an important substrate for arboreal lichens and, in humid forests, for mosses. Thus, depending on your definition of forest "health", an adequate inventory of snags in various conditions may be required for a healthy forest.

Much of the early work and ideas about snags came from studies in humid, productive coastal forests characterised by infrequent stand replacing disturbance. Snags tend to be large diameter and persistent in such forests. Snags in slow growing and frequently disturbed boreal stands can have a different character and ecological role – smaller, less persistent. It is important to describe and interpret the character, abundance, condition (and the variation therein) of snags in the pre-mining area so that snag targets can be established.

Constrained/unconstrained

Inventorying snags is relatively easy and inexpensive. Ecosystem models should be used to predict the anticipated production of snags in the stands on reclaimed mined land.

Spatial and temporal variability

Snag abundance and condition will vary over time as the stand passes through different development phases and successional stages. Spatial variability will reflect spatial patterns of tree mortality. Temporal variability should be addressed through modeling. Spatial variability should be documented in mature pre-mining stands to establish characteristic spatial patterns of mortality, by ecosystem type.

Measurement and Monitoring Program

Measure	Msrmnt unit	Min/Max Values (Targets) /Expected Trends	Information sources *Where do you get the data?*	Methodologies to determine values (including spatial assessment)	Interpretation *What do the data show?*	Frequency of data collection	Link ages
Snags	Number of snags per size class per ha; stage of decay	Max/min values established by studies on a catena of site qualities in un-mined areas. Temporal fingerprint established by ecosystem management model	**NRV established by data collection in pre-mined stands. Future trend predicted by model**	Model calibration, validation and gaming	Temporal fingerprints of snags by species, size and condition to act as a benchmark for field monitoring far in the future	Initial model calibration.	

Appendix 2

INDICATORS OF ECOSYSTEM FUNCTION
FOR RECLAIMED OIL SANDS SITES

Indicator: Forest Floor (FF) Development and Turnover (Ecological Process Measurement)

Scientific Rationale

- A description / argument as to why this indicator is a comprehensive and effective "indicator" of ecosystem function with respect to assessing reclamation success.

- The forest floor is a layer of nutrient-rich, biologically-active organic matter that develops at the soil surface as a result of the input of dead plant residues (a consequence of plant productivity) and the enzymatic action of the soil decomposers on those residues. Therefore, it integrates the activities of both the primary producers and the decomposers.
- The products of litter decomposition (mineralized nutrients, stable organic matter) are critical to the long-term sustainability of both the primary producers, the soil decomposers and the mycorrhizal symbionts.
- The forest floor represents a nutrient and microbial (mycorrhizal, N-fixing) pool that is critical to a self-sustaining plant cover. Linked to soil fertility.
- The forest floor is important in controlling soil moisture regimes since organic matter is effective in retaining precipitation.
- The forest floor provides a matrix for biological activity and healthy root growth.
- The forest floor is an indicator of forest stability, since forest floor development (i.e. organic matter accumulation) tends to stabilize as the forest community stabilizes.
- Reclamation success is dependent on the establishment of a self-sustaining plant community, and the sustenance of this plant community is inextricably tied to the forest floor.

Constrained/Unconstrained

1. <u>Operational ease</u>: Simple and straightforward.
2. <u>Sampling Clarity</u>: Easy to develop protocol and standardize; easy to maintain consistency in measurements over time.

3. Cost: Inexpensive; primarily labor.
4. Effectiveness monitoring recommendations:
   - measure primary productivity in association with forest floor development since one depends on the other (forest floor and associated microbiota depend on degree of primary production for its development, while primary producers depend on the forest floor for nutrients and microbial functions (mineralization, symbionts).
   - measure litterfall or litter input for the reasons already cited; this will allow calculation of litter turnover if considered in conjunction with organic matter accumulation in forest floor.
   - separate litter, fermentation and humus (LFH) layers when assessing forest floor development. The layers represent different stages of decomposition so can indicate the decomposability of the incoming litter and the rate of production of stable organic matter (e.g. humus).
   - analyse LFH layers or forest floor material for C, N, P and other elements to allow estimation of plant-required nutrient pools.
   - sample at the same time of the year on each monitoring event, possibly at two times of the year - the time of maximum litter input and the time of minimum litter input.

Measurement and Monitoring Program

Measure	Msrmnt unit	Min/Max Values (Targets) /Expected Trends	Information sources *Where do you get the data?*	Methodologies to determine values (including spatial assessment)	Interpretation *What do the data show?*	Frequency of data collection	Linkages
Forest floor oven dry mass, dry mass of separate LFH layers	g or kg m^{-2} kg ha^{-1}	Increase over time Jack Pine = Boreal mixedwood =	**Field measurements** **Reclamation reports**	- Establish monitoring plots. - Excavate surface organic (OM) layer using cores or quadrats located along randomly placed transects in plots. - Separate OM from underlying mineral soil and sort into LFH layers, oven dry, weigh, calculate mass/unit area. Determine loss on ignition to allow conversion to ash-free basis.	- The rate of accumulation of stable organic matter (humus) that is important for long-term soil fertility. - Indicates when ecosystem is relatively stable (little change in FF mass over time)	First year after site establishment; every 3-5 years thereafter	- Primary production (litter input) - FF respiration - FF microbial biomass C. - Soil nutrients (N, P). - Litter decay

Organic matter accumulation as carbon	as above	Increase over time. Stabilizes as plant community stabilizes. boreal mixedwood = 1.7-3.5 kg C m^{-2}**	**as above**	- carbon analysis on dried forest floor material or separated LFH layers.	as above	as above	as above

Plus information on:

- Variability – high spatial and temporal variability during the early stages of ecosystem development, but this should decrease with time as forest stabilizes and carbon inputs (litterfall) and outputs (respiration) stabilize.
- Documentation of where single use of an indicator would be considered inappropriate.

Indicator: Soil Fauna Diversity Index (Diversity Measurement)

Scientific Rationale:

- Both surface- and soil-dwelling macrofauna (beetles, spiders, ants, earthworms) and forest floor mesofauna (mites, springtails) represent a wide variety of functional groups and different trophic levels.
- Soil fauna are indicators of ecosystem function because of their roles in decomposition and nutrient cycling. They have been shown to accelerate litter decomposition, and increase rates of nutrient mineralization by increasing the surface area of plant residues available for microbial attack and by stimulating the microbiota through grazing and dispersal activities.
- They can have high reproductive potential (e.g. springtails) and <u>short generation times which allow them to respond rapidly to changes in soil structure as a result of reclamation activities</u>. Sensitive to soil perturbations and soil improvement resulting from vegetation establishment and forest floor development.

Constrained/Unconstrained

1. <u>Operational ease</u>: Relatively easy to extract from soil and identify to suborder level; great deal of expertise required to identify to genus/species level. Requires extractor, stereo- and light microscopes. Samples can be stored for months following extraction.
2. <u>Sampling Clarity</u>: Easy to develop protocol and standardize; the same observer should be retained to maintain consistency in measurements and identification amongst sample times. Large number of samples required to reduce variability caused by natural aggregation of the fauna.
3. <u>Cost</u>: May be expensive due to requirement for labor with expertise in mesofauna identification, which is especially important if large numbers of samples require processing.
4. <u>Effectiveness monitoring recommendations</u>:
    - baseline data required on mesofauna community structure and composition in undisturbed reference sites for comparison with sites in various stages of reclamation. An understanding of mesofauna communities in undisturbed sites is critical to evaluating the mesofauna diversity status in soils at various stages of reclamation as determined by statistical methods such as analysis of variance, cluster analysis, and detrended correspondence analysis. Also, some species may be sensitive indicators of reclamation success, but this can be evaluated only if considered against fauna communities characteristic of reference sites.
    - data on seasonal effects on community structure and composition are required since abundances of various species can vary tremendously depending on moisture/temperature conditions and phenology of individual species. Seasonal variability, especially in aggrading ecosystems, may confound patterns of reclamation success as determined by this measurement.

- since soil fauna are dependent on organic matter and the microbiota associated with it, mesofauna assessments can be linked to ecological processes such as forest floor development, nutrient pools (cycling) and soil respiration, and microbial diversity measurements.

Measurement and Monitoring Program

Measure	Msrmnt unit	Min/Max Values (Targets) /Expected Trends	Information sources *Where do you get the data?*	Methodologies to determine values (including spatial assessment)	Interpretation *What do the data show?*	Frequency of data collection	Linkages
Macrofauna (beetles, ants, spiders etc.)	number g^{-1} dm or m^{-2} macrofauna: id to family, genus, species level. Mesofauna: id to suborder, genus, species level	**- increase in abundance over time and with increasing organic matter content** - increase in species diversity with time - stabilization of community structure with time and movement towards community patterns in reference sites.	**Field measurements** **Literature** **Fauna collections and databases**	- Macrofauna: pitfall traps in established plots that can be revisted for monitoring purposes. ID by microscopic examination. - High spatial variability may necessitate, preliminary assessment in reference site to determine sampling intensity.	- Point in restoration process that fauna diversity and community structure are approaching that in reference site. - Maturity of site in relation to plant community and forest floor/nutrient pool establishment, which in turn control fauna community development. - Change in mesofauna functional groups with time, since suborder identification is roughly related to function	First year following establishment of reclaimed site. Every 3-5 years thereafter.	-Plant community structure and abundance. - FF, organic matter, nutrients- - soil respiration - microbial biomass
Mesofauna (mites, springtails) abundance, diversity, community structure and functional groups.	number g^{-1} dm or m^{-2} Mesofauna: id to suborder, genus, species level			- Mesofauna: cores from established plots, extraction and microscopic examination in laboratory.			

Plus information on:

- Variability – spatial and temporal variability are high for these measurements, therefore necessitating intense (high replication) sampling - more than one sampling time for each monitoring event. Also, may require preliminary studies in reference site to establish appropriate sampling design.
- Documentation of where single use of an indicator would be considered inappropriate.

Indicator: Microbial Diversity Index (Diversity Measurement)

Scientific Rationale:

- The soil microbiota, dominated by the bacteria and fungi, are a critical component of the soil food web in that they control the degradation of plant residues, and, in so doing, mineralize nutrients (N, P) essential for plant growth.
- Soil microbial biomass plays an important role in the immobilization of nutrients such as N and P. The retention of nutrients is critical to soil fertility and ecosystem sustainability, especially in nutrient-deficient soils.
- Soil microorganisms respond rapidly to changes in soil properties, and, therefore, are good indicators of soil quality.
- The soil microbial biomass is species-rich and has a high functional diversity that can be a valuable monitoring tool for determining when microbial community structure and diversity approach that in an undisturbed reference site.
- The soil microorganisms are important agents in the production of stable organic matter which underpins sustainable forest ecosystems.

Constrained/Unconstrained

1. Operational Ease: Microbial biomass is relatively easy to measure in the laboratory using the substrate-induced respiration (SIR) method or the chloroform fumigation extraction method. Measures of microbial community structure (species richness, diversity, evenness etc.) and functional diversity are more labor intensive and require a higher degree of expertise. Interpretation of community structure measurements can be difficult due to bias in the methods.
2. Sampling Clarity: Extraction of organisms from the soil may be severely biased due to lack of methods to extract and identify all microorganisms in a particular soil sample. In order to reduce high variability inherent in microbial diversity measurements, thorough homogenization of the soil sample is required prior to extracting or isolating microorganisms, or prior to measuring microbial biomass.
3. Cost: Relatively inexpensive for microbial biomass measurements, but access to a respirometer or carbon analyzer is necessary. Microbial diversity measured using low tech isolation methods are labor-intensive and require a high level of expertise. High tech

chemical/molecular methods (DGGE, PLFA, RISA) require expertise, chemicals and specialized equipment (e.g. gas chromatograph) to determine microbial community fingerprint patterns or relative contributions of bacteria and fungi to the microbial biomass.

4. Effectiveness monitoring recommendations:

- methods are subject to bias because they often target only specific components (Gram negative bacteria, Gram positive bacteria, actinomycetes, fungi) of the microbial biomass. Therefore, a comprehensive microbial diversity measurement requires a combination of methods.
- difficult to link microbial community structure measurements (richness, abundance) with functional attributes. Attempts are being made to do this by linking Biolog® measurements with community structural measures such as PLFA profiles.
- microbial biomass C measurements do not provide insight into the relative contributions of the various microbiota to the decomposer community; however, they can be a sensitive indicator of microbial response to reclamation procedures. Also, this measure is relatively straightforward and usually linked to the quality and quantity of organic matter in the soil profile, which, in turn is related to plant success and forest floor development in an aggrading ecosystem. Coupled with soil respiration, microbial biomass measurements allow the calculation of the metabolic coefficient (respiration/unit amount of biomass C), which is related to the stability of organic matter.
- an appropriate reference site is essential for monitoring microbial diversity in reclamation sites, because, without a reference site, it is impossible to determine when microbial community structure in a reclamation soil is approaching that in an undisturbed soil.

Measurement and Monitoring Program

Measure	Msrmnt unit	Min/Max Values (Targets) /Expected Trends	Information sources *Where do you get the data?*	Methodologies to determine values (including spatial assessment)	Interpretation *What do the data show?*	Frequency of data collection	Linkages
Community structure/ diversity	Relative bacteria, fungal, actino. composition of microbial community 1.PLFA:– nmol g^{-1} dm soil **2. DGGE: community specific band patterns; fingerprint patterns** 3. RISA: fingerprint patterns;	1. PLFA: increase in fungal biomass with development of F layer in FF; decrease in fungi and increase in bacteria with increase in site fertility. Fungal:bacterial PLFA in poor pine site FF = 0.3-0.6 2. DGGE and RISA band profiles in reclamation soil become more similar to those in undisturbed soil with time and FF development.	**Field measurements**	FINGERPRINTING METHODS: 1. phospholipid fatty acid (PLFA) profiles (membrane lipids vary with specific microbial groups; only found in viable microbes) 2. denaturing gradient gel electrophoresis (DGGE) on soil-extracted DNA for bacterial communities. Similarity determined amongst fingerprint patterns and analyzed by principal component analysis (PCA). 3. ribosomal intergenic spacer analyis (RISA) of soil-extracted DNA for	1.PLFA: changes in relative amounts of Gram – and Gram + bacteria, fungi, actinomycetes in aggrading soil. 2. DGGE: changes in bacterial community fingerprints, i.e. composition and structure with time. 3. RISA: changes in bacterial and fungal community composition with time and treatment.	1st yr after site establishment, every 3-5 years thereafter	- Soil organic matter - Soil respiration - Microbial biomass C - Substrate utilization (Biolog®) - Soil nutrients (available and total N and P)

	4. Direct isolation – no. of species; species abundance	4. Number of species increase with time of reclamation, while relative abundances and evenness become more stable, and approach that in reference site.		bacterial and fungal communities. Fingerprint similarity determined and analyzed by PCA. **DIRECT ISOLATION METHOD:** 4. Direct isolation of bacteria and fungi on synthetic media followed by identification by morphological or biochemical methods.	For all of above, similarity between reclamation and undisturbed sites determined by PCA. 4. Direct: When does microbial community structure (species richness, diversity, evenness) approach that in undisturbed reference soil.		
Functional diversity	Community level physiological profile based on color intensity in each substrate measured as absorbance @ 590 nm.	1. increase in functional diversity with time and FF development; stabilization of functional diversity with time.	**Field measurements** **Literature**	1. Biolog® plates (utilization by viable Gm- bacteria of 95 specific C sources)	1. potential of bacterial biomass to utilize different carbon substrates; change in C substrate utilization patterns with time and FF development; similarity/differences in substrate utilization patterns between reclamation and reference soil .	1st yr after site establishment, every 3-5 years thereafter	- as for community structure and diversity
Microbial biomass C	μg or mg biomass C g^{-1} dm soil, g m^{-2}, kg ha^{-1}	- increase in biomass with increase in FF development or organic matter accumulation; decline in biomass with soil depth. JP FF = 7-17mg biomass C g^{-1} dm JP 0-5 cm Min: = 0.2-0.4 mg bio C g^{-1} dm	**Field measurements** **Literature**	1. chloroform fumigation-extraction (difference in soluble C between fumigated and unfumigated samples) 2. Substrate-induced respiration (SIR) (microbial response to glucose addtion)	-microbial energetics in an aggrading ecosystem; organic matter decomposition potential.	1st yr after site establishment, every 3-5 yrs thereafter	- as for community structure and diversity

Plus information on:

- Variability – community structure measurements (e.g. species richness, abundance) are inherently highly variable both spatially and temporally. Variation may be particularly high in the early stages of soil reclamation, when forest community and forest floor development are in their infancy. Microbial biomass C measurements tend to be less variable, because this measure does not distinguish the various components of the biomass. A minimum of 5 replicate samples/soil layer/site is required for any of the microbial diversity measurements. Compositing subsamples within samples can reduce variability.
- Documentation of where single use of an indicator would be considered inappropriate.

Indicator: Mycorrhizae (Diversity Measurement)

Scientific Rationale

- Over 90% of higher plant roots normally form symbiotic associations with fungi.
- Mycorrhizal fungi are essential to the establishment, growth and reproduction of higher plants, especially in nutrient-poor soils such as those characteristic of the boreal forest.
- Mycorrhizal fungi increase the plant nutrient supply leading to greater yield and nutrient accumulation in the vegetation. Plant roots can be very inefficient at acquiring sufficient N and P to support their growth, especially in nutrient-poor soils. Through their large network of fine, filamentous hyphae, mycorrhizal fungi are more effective than plant roots at permeating large volumes of soil and acquiring plant-essential nutrients such as N and P. These nutrients are tranferred to the plant for its growth and reproduction, while the plant, in turn, provides the fungus with a source of carbon in the form of sugars.
- Mycorrhizae are important in protecting the plant from soil-borne pathogens and parasites and environmental extremes caused by drought, high soil temperatures, salinity and pH. In addition, mycorrhizal fungal networks, are essential components of nutrient cycling processes because of their roles in nutrient immobilization, carbon transfer, carbon storage, soil aggregation, and nutrition of mammals and invertebrates.
- It would be expected in an oil sands reclamation scenario that the benefits provided by the mycorrhizae would be critical to the establishment, health and sustainability of a plant cover, especially in sites where the soil nutrient supply is low and the plants are exposed to adverse environmental conditions (e.g. drought, salinity).
- Soil disturbance, such as mining, can reduce mycorrhizal inoculum potential and alter mycorrhizal community structure drastically.

Constrained/Unconstrained

1. Operational Ease: Boreal forests are dominated by three main mycorrhizal types: 1) ectomycorrhizae; 2) arbuscular mycorrhizae and 3) ericoid mycorrhizae, and methodologies required to assess these mycorrhizae vary. In all cases, it is necessary to separate the roots and/or spores (AM mycorrhizae) from the soil which is time-consuming, and requires some expertise with regard to recognizing root or spore types. Total abundances of ectomycorrhizae and ericoid mycorrhizae are relatively easy to measure requiring only a stereomicroscope to count the total number of short roots in a sample or subsample that have formed mycorrhizae. Arbuscular mycorrhizal abundance measurements are more time-consuming since roots must be cleared and stained before AM assessment under a light microscope. Mycorrhizal diversity assessments necessitate identification of the fungi forming the mycorrhizae – a process that is based on morphological features alone or on a combination of morphological features and molecular properties of fungal tissue (ecto- and ericoid mycorrhizae) or spores (AM mycorrhizae). Regardless of the methodology, measurements of mycorrhizal diversity are costly, requiring a great deal of time and expertise.
2. Sampling clarity: In forests, soil cores removed randomly from plots or along transects are generally used to assess mycorrhizal status in the field. Mycorrhizal inoculum potential in a reclamation soil can be addressed in the laboratory using a baiting method in which relevant plant species are grown in test soil under controlled conditions, and mycorrhizal development is evaluated after a suitable period of plant

growth. Due to the time-consuming nature of both field and laboratory assessments, the number of samples and amount of soil investigated for mycorrhizal status are usually very low, relative to the area of the site. Also, species diversity (community structure) measurements tend to be highly variable, unless a forest soil is dominated by a low number of mycorrhizal fungi. Total % mycorrhizal colonization measurements are less variable but can be of limited use if the soil contains sufficient mycorrhizal inoculum – in this case mycorrhizal colonization will always be near or at 100%. Nevertheless, the mycorrhizae are so critical to the health of the plant cover, that they should be included in a monitoring program, at least during the early stages of forest development.

3. Cost: Screening for the presence or absence of mycorrhizae in a reclamation site is relatively inexpensive; more detailed assessments of mycorrhizal fungal diversity can be very costly for the reasons outlined above.

4. Effectiveness monitoring recommendations

- Conduct a detailed baseline survey of ectomycorrhizal and arbuscular mycorrhizal potentials in reclamation soil and a comparable reference soil prior to planting to establish the presence and identity of mycorrhizal inoculum. May be addressed in a laboratory baiting study.
- Monitor reclamation plant species to determine rate of mycorrhizal colonization. May be addressed in the laboratory under controlled conditions, but should be supported by field measurements.
- On each monitoring date, evaluate as many replicate root systems or soil cores as possible to improve precision of the mycorrhizal community composition (species richness). Combining many replicate samples in to one composite sample may be one approach for reducing variability.
- Monitor annually during the initial stages of plant establishment and every 5 years thereafter.

Measurement and Monitoring Program

Measure	Msrmnt unit	Min/Max Values (Targets) /Expected Trends	Information sources *Where do you get the data?*	Methodologies to determine values (including spatial assessment)	Interpretation *What do the data show?*	Frequency of data collection	Linkages
AM colonization	% root colonized with arbuscules, vesicles, AM hyphae	Increase in % root length colonized and rate of colonization with time of reclamation	**Field measurements** **Laboratory measurements** **Literature**	- Remove random plants or soil cores from field plots or along transects (10 min/site). - Separate AM roots (usually grasses or herbs) from soil. - Clear and stain roots. - Mount roots on slide and examine	-Arbuscular mycorrhizal colonization potential of a reclamation soil relative to that in a comparable reference site.	Detailed initial survey; annually for first 3 years after plant establishment; every 3-5 yrs thereafter	-Plant productivity as shoot ht, shoot wt, root length, root wt. - Nutrients in

				microscopically. - Assess % root length colonized by AM fungi.			soil and plant biomass.
AM diversity	No. of AM species	Increase in AM diversity with time; stabilization of community structure with time	**Field and lab measurements** **Literature**	- Sample soil as for AM colonization. - Extract AM spores using sieving and centrifugation methods. - ID AM fungi using spore morphology or molecular methods or combination of both; also check roots for fungi that don't produce spores such as the "fine endophyte".	- Change in AM species richness in reclamation soil with time, and degree of similarity or difference from reference soil. Point at which AM community structure stabilizes.	As for AM colonization	As for AM colonization, plus soil organic matter content.
ECM/Ericoid colonization	% root tips converted to ECM or ericoid mycorrhizae	Reduced ECM colonization in reclamation soil immediately following planting; rapid increase in ECM inoculum once plants are established.	**as for AM measurements**	- As for AM colonization. - Separate roots ((conifers, aspen, alder, blueberry, bearberry) from soil (washing). - Subsample roots, scan under stereomicroscope and count no. of ECM and non ECM root tips. - Confirm mycorrhizal presence with light microscope, if not discernable with stereomicroscope.	- ECM mycorrhizal potential of reclamation soil relative to reference soil. - Change in ECM abundance over time. - Relationship to plant health measures (shoot production, nutrient content)	As for AM colonization	As for AM colonization

ECM/Ericoid diversity	No. of ECM species and relative abundance of each species.	ECM community in early stages of forest development dominated by non-specialist multi-host species and low number of species. Number of ECM species increases with age of forest, and community structure stabilizes as plant community stabilizes	**as for AM measurements**	- Separate ECM or ericoid roots (conifers, aspen, alder, blueberry, bearberry) from soil cores removed randomly from monitoring plots. - Place roots in water sort mycorrhizae into morphological groups using stereomicroscope - With light microscope identify mophotypes using mantle and hyphal characteristics and published decriptions of mycorrhizal species. - To improve precision of identification use molecular techniques (extract DNA from mycorrhizae, use polymerase chain reaction (PCR) to amplify specific portion of DNA, characterise by restriction length polymorphism (RFLP) or DNA sequences, compare with RFLP or DNA sequences from identified fungi).	- Abundances of ECM species (community structure) in reclamation soil relative to undisturbed soil. - Differences/similarities in ECM communities between reclamation and reference soils. Stage at which ECM community composition and structure approaches that in reference soil.	As for AM colonization	As for AM colonization

Plus information on***:***

- Variability – spatial variability tends to be high for ECM/ericoid species diversity which may mask community structure properties; spatial variability for AM species may be lower since fewer fungi form AM than ECM or ericoid mycorrhizae. Temporal variability may be high during the initial stages of forest development, but should stabilize as forest composition and growth stabilizes.
- Documentation of where single use of an indicator would be considered inappropriate.

Indicator: N-Fixing Symbionts (Ecological Process Measurement)

Scientific Rationale

- Legumes and actinorhizal shrubs form symbiotic associations not only with mycorrhizal fungi (AM in the case of legumes; ECM or AM in the case of shrubs) but also with N_2-fixing bacteria (*Rhizobium* in the case of legumes; *Frankia* in the case of woody shrubs).
- N_2-fixing plants are considered excellent candidates for mine site reclamation because through their nitrogen-fixing abilities they are able to tolerate inhospitable conditions while improving soil fertility and organic matter status.
- In the oil sands region, various native legumes and actinorhizal shrubs (alder, Canadian buffalo-berry) should be considered for mine site reclamation because of their ability to accrue nitrogen in what are often infertile soils.
- Reconstructed soil used for mine site reclamation may be deficient in N_2-fixing symbionts, thereby constraining the establishment of N_2-fixing plants. This applies particularly to actinorhizal shrubs, which are difficult to establish and will not grow if the soil lacks the *Frankia* symbiont.
- Alder and Canadian buffalo-berry are commonly associated with conifer and mixedwood forests in the boreal forest; their establishment, in conjunction with tree species, would accelerate the rate of revegetation, soil development and fertility and community/ecosystem recovery on oil sands mine sites.

Constrained/Unconstrained

1. <u>Operational ease</u>: Laboratory baiting studies are relatively easy to conduct and provide valuable information on the quality and quantity of either *Rhizobium* or *Frankia* inoculum in soil. Under controlled conditions, legumes or actinorhizal shrub species are grown in test soil and evaluated for nodule development after a suitable period of time (e.g. 3 months). Nodules are readily recognizable and are pink or reddish when actively fixing nitrogen.
2. <u>Sampling Clarity</u>: Relatively straightforward; replicate soil samples from reference and reclamation sites are placed in containers, planted and assessed for nodule formation. Does not require a high level of expertise.
3. <u>Cost</u>: Relatively inexpensive since it doesn't require a high degree of expertise or sophisticated equipment, unless an assessment of N_2-fixing activity is required, necessitating use of a gas chromatograph and requirement for a higher level of expertise.
4. <u>Effectiveness monitoring</u>:

- Screen for nodule-development potential across the mine site prior to planting N_2-fixing plants.
- Check containerized plants (e.g. alder) for presence of nodules prior to outplanting.
- If inoculum is lacking, consider artificial inoculation or amendment with native soil containing high inoculum potential of N_2-fixing symbionts.

- Relate shoot and root production of test species with nodule development both in the laboratory and field.

Measurement and Monitoring Program

Measure	Msrmnt unit	Min/Max Values (Targets) /Expected Trends	Information sources *Where do you get the data?*	Methodologies to determine values (including spatial assessment)	Interpretation *What do the data show?*	Frequency of data collection	Linkages
N_2-fixing nodules	no. or mg dm nodule/ plant or /g dm root.	Increase in nodule mass, N_2-fixation and FF nitrogen with time until the forest stabilizes	**Field and laboratory measurements** **Literature**	- Screen soil for N_2-fixing inoculum using bait plants in test soil in laboratory bioassays. - After growing plants for 2-3 months, survey roots for nodule development. - Count nodules, evaluate color and/or determine nodule mass. - Measure shoot and root dm. - Excavate plants in the field and ascertain nodulation status.	- Presence/absence of N_2-fixing symbionts. - Effectiveness of symbionts in promoting plant growth. - In the field, N_2-fixer effect on soil fertility, N accumulation, ecosystem recovery. Also effects of reclamation procedures on N_2-fixer.	**- Detailed pre-planting assessment.** **- Annually for 3 years, every 3-5 yrs thereafter.**	- Plant productivity. - FF development - OM and N accumulation
N_2-fixation	- µg or mg N fixed/unit of nodule mass -kg N fixed ha^{-1}	Increase with time of reclamation	**Field and laboratory measurements** **Literature**	- reduction of acetylene to ethylene by nitrogenase in N_2–fixing nodules measured by gas chromatograph. - can be applied to both laboratory and field-grown plants	-N_2 fixing potential of a site - potential contribution of N_2-fixing plants to soil N pool.	During establishment of N_2-fixing plants; every 3-5 years thereafter.	- Plant productivity - FF floor development - soil OM and N accumulation - soil fertility

Plus information on:

- Variability – high temporal and spatial variability anticipated for N_2-fixation measurements, especially during the early stages of soil reclamation. Assessments of N_2-fixing nodules probably less variable, but still relatively high during the early phases of plant establishment.
- Documentation of where single use of an indicator would be considered inappropriate.

Appendix 3

INDICATORS OF ECOSYSTEM FUNCTION FOR RECLAIMED OIL SANDS SITES

Indicator: Litter Quality

Scientific Rationale

Litter quality is an important indicator of ecosystem function mainly because of the following two reasons: 1) litter quality reflects the soil/site condition on which the plant species grow, and 2) litter quality affects the rate of litter decomposition, soil organic matter build-up, soil nutrient dynamics, and ultimately the soil/site condition. Controls of litter quality on soil nutrient (N in particular) cycling and availability play a major role in the sustainability of ecosystems being established on the reclaimed sites. In litter samples, macronutrients other than N may be lacking and may thus also limit the decomposition of litter and the subsequent cycling of nutrients (Berg 2000). The long-term build-up of soil organic matter is positively influenced by the quality, and rate and pattern of litter decomposition (Berg et al. 2001). Litter quality will be species specific, so measures of the litter quality indicator that may be developed have to be species specific. With the establishment of species specific measures of litter quality, this indicator should provide a very helpful indication of ecosystem processes and how they are being changed by disturbance or reclamation processes.

Constrained/Unconstrained

Litter quality would be a constrained indicator. Litter samples are operationally feasible to collect and sampling clarity is good as long as a very well designed protocol is followed. The cost for acquiring the information needed for this indicator very much depends on the type of measures to be adopted. Cost for the analysis is generally in the low to medium range, from about $10 to $50 per sample, depending on the analysis to be made. The cost for setting up litter traps for the field collection of litter samples can be substantial, especially if the sites are remote and access is difficult. Direct litter sample collection off the forest floor surface is possibly a cheaper method to acquire litter samples. Comparison across sites should be valid as long as a consistent protocol is applied.

Research specific to plant species and sites in the oil sands is required in order to apply this indicator to effectively monitor the effectiveness of reclamation success.

Measures and Monitoring Program

Measure	Msrmnt unit	Min/Max Values (Targets) /Expected Trends*	Information sources *Where do you get the data?*	Methodologies to determine values (including spatial assessment)	Interpretation *What do the data show?*	Frequency of data collection†	Linkages
Litter N concentration	mg/g	Lodgepole pine: 4.5-7.3 Paper birch: 7.0 Trembling aspen: 7.3	**Thomas and Prescott 2000** **Stump and Binkley 1993**	Dry combustion or wet digestion and Kjeldahl	Close correlation with soil N availability and N cycling rates Positive correlation with litter decomposition rates	annual	NA‡
Lignin concentration	mg/g	Lodgepole pine: 253-308 Paper birch: 257 Trembling aspen: 194	**Thomas and Prescott 2000** **Stump and Binkley 1993**	Acid digestion fibre method	Negative correlation with N mineralization rates	annual	NA

			Goering and van Soest 1970				
Tannin concentratio n	mg/g	Lodgepole pine: 245 Paper birch: 55 Black spruce: 25	**Thomas and Prescott 2000** **Lorenz et al. 2000** **Porter et al. 1986**	Acetone extraction and butanol-HCl method	Negative correlation with N mineralization rates	annual	NA
Polyphenol concentratio n	mg/g	Populus nigra: 40 Alnus glutinosa: 27	**Pereira et al. 1998** **Reed et al. 1985**	Gravimetric method of precipitation with trivalent ytterbium acetate	Negative correlation with N mineralization rates	annual	NA
C:N ratio	unitless	Lodgepole pine: 70-111 Paper birch: 72 Trembling aspen: 71	**Thomas and Prescott 2000** **Stump and Binkley 1993**	By calculation	Close correlation with N mineralization rates	annual	NA
Lignin:N ratio	unitless	Lodgepole pine: 41-57 Paper birch: 37 Trembling aspen: 28	**Thomas and Prescott 2000**	By calculation	Negative correlation with N mineralization rates	annual	NA

			Stump and Binkley 1993				
Concentrations of other nutrients (e.g. P, K, S, B, etc)	mg/g	P Lodgepole pine: 0.6 Paper birch: 2.5	**Thomas and Prescott 2000**	Wet digestion and ICP or atomic absorption	Related with their availability in the soil	annual	NA

*: Min/max values for litter quality indicators are species specific. Values provided here are some indicative values.
†: Sampling intensity expected to be annual but can be reduced to every three to five years for long-term monitoring of reclamation success.
‡: Not applicable

Plus information on:

- Variability – spatial and temporal variability considerations
- Documentation of where single use of an indicator would be considered inappropriate.

Variability: spatial variability is expected, therefore, multiple collectors need to be set up in a single plot. Recommended number of collectors is a minimum of six collectors for a 20 x 20 m plot. Temporal variability can be caused by changes in annual climatic conditions and the development of plant (age). The recommended annual assessment above applies to the early years (e.g., within the first five years) after reclamation. Thereafter, the frequency of monitoring can be reduced.

Single use: Even though this indicator can be considered a good representation of several ecosystem functions and processes, single use may not be appropriate. For example, contradictory results have been reported about relationships between litter quality measures and ecosystem processes, for example, Thomas and Prescott 2000 found lignin:N ratio, N concentration and C:N ratio of litter to be poor predictors of net N mineralization in the soil, while other studies have found the lignin:N of litter to be a good predictor of net N mineralization rates in the soil (Gower and Son 1992; Scott and Binkley 1997).

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Indicator: Foliar nutrition

Scientific Rationale

Foliar nutrient concentration is directly related to the health of plant species in most situations. Deviations can occur where luxurious nutrient uptake has occurred or limiting factors other than nutrients are controlling the growth of plants (Havlin et al. 1999). Foliar nutrition is very much related to the litter quality indicator, i.e., there may be direct correlations between foliar nutrition and litter quality measures, such as litter nutrient concentrations, C:N ratio, lignin concentrations, and lignin:N ratio, even though some research have showed that the relationship between leaf nutrient status and litter nutrient concentration may be weak (Aerts 1996).

The most important nutrients (that most likely will be limiting) are N and P (Chapin 1980). Other nutrients that may be limiting will depend on the minerarology, degree of soil development, mycorrhizal associations, competition, climate, and soil physical, chemical, and biological conditions. As such, foliar nutrition may provide an indication of the overall growth condition as mediated by the range of factors mentioned above, and thus could be one of the effective indicators of ecosystem functioning.

Constrained/Unconstrained

Foliar nutrition would be a constrained indicator. Foliar nutrition can be an indicator that can be routinely monitored, particularly when clear objectives were formulated before the monitoring program is implemented. Foliar samples are operationally feasible to collect and sampling clarity is good as long as a very well designed protocol is followed. Standard sampling protocols are available. Most of those call for collecting foliar samples from the upper one third of the crown, and collecting fully expanded, sun-lit leaves in the dormant or in the least physiological active season. Cost for the analysis is generally in the low to medium range, from about $10 to $50 per sample, depending on the exact analysis to be made. If the cost for field travel and sampling is factored in, the total cost for the monitoring program will be much higher, especially if the sites are remote and access is difficult. Foliar sampling of large trees can be much more difficult and expensive than collecting litter samples.

Research specific to plant species and sites in the oil sands is required in order to apply this indicator to effectively monitor the effectiveness of reclamation success. Knowledge of baseline data, spatial variability, and relationships between foliar nutrition and basic soil properties can assist in the establishment of an effective monitoring system.

Measures and Monitoring Program

Measure	Msrmnt unit	Min/Max Values (Targets) /Expected Trends*	Information sources *Where do you get the data?*	Methodologies to determine values (including spatial assessment)	Interpretation *What do the data show?*	Frequency of data collection†	Linkages
N concentration	mg/g	Black spruce: 6-13 Tamarack: 10-40 Lodgepole pine: 11-15	**Mugasha et al. 1999** **Mead 1984**	Dry combustion or wet digestion and Kjeldahl	Close correlation with soil N availability and N cycling rates Positive correlation with litter quality	Annual / every five years	NA‡
P concentration	mg/g	Black spruce: 1.5-2.5 Tamarack: 2-9 Lodgepole pine: 1.2-1.5	**Mugasha et al. 1999** **Mead 1984**	Wet digestion and colorimetric or ICP	Direct correlation with soil P availability	Annual / every five years	NA
S concentration	mg/g	Lodgepole pine: 0.78-1.02	**Brockley 2004**	Wet digestion and ion chromatograph	Direct correlation with soil S availability	Annual / every five years	NA

B concentration	µg/g	Lodgepole pine: 6-29	**Brockley 1990**	Wet digestion and ICP	Correlation with soil B availability	Annual / every five years	NA
Nutrient ratios	unitless	Species specific	**Walworth and Sumner 1987**	Depending on nutrients of interest	Can identify nutrient deficiencies or nutrient imbalance	Annual / every five years	NA
Vector analysis	NA	Species specific and based on experimental results	**Timmer and Munson 1991; Imo and Timmer 1999**	Depending on nutrients of interest	Can identify nutrient deficiencies through evaluating plant species response to nutrient additions	Annual / every five years	NA
DRIS analysis	NA	Species specific and indices needs to be established through research	**Walworth and Sumner 1987; Lozano and Huynh 1989**	Depending on nutrients of interest	Can establish norms of DRIS indices and apply those to unknown stands to identify nutrient limitations	Annual / every five years	NA

*: Min/max values for foliar nutrition are species specific

†: Sampling intensity expected to be annual but can be reduced to every three to five years for long-term monitoring of reclamation success.

‡: Not applicable

Plus information on:

- Variability – spatial and temporal variability considerations
- Documentation of where single use of an indicator would be considered inappropriate.

Variability: spatial variability is expected, as is the case with the litter quality indicator; therefore, foliar samples need to be collected from multiple trees per stand/site. Recommended number of trees to be sampled is a minimum of 15 trees per standard forestry plot (Ballard, T., pers. commu.). Multiple plots may need to be established if the area to be evaluated is more than several hectares. Temporal variability can be caused by changes in annual climatic conditions and the development of plant (age). The recommended annual assessment above applies to the early years after reclamation. Thereafter, the frequency of monitoring can be reduced to once every five years.

The spatial variability of this indicator is expected to be less than that of soil nutrients, as discussed below, due to the fact that tree root system is expansive and the root system takes up nutrients from a large area of soil and the spatial variability is integrated in foliar nutrient parameters.

Single use: Even though this indicator can be considered a good representation of several ecosystem functions and processes, single use may not appropriate. For example, contradictory results have been reported about relationships between foliar nutrition and ecosystem processes or responses to nutrient additions (McNeil et al. 1988; Garrison et al. 2000), foliar nutrient concentration or some of the other proposed measures alone do not provide an adequate indication of forest stand nutrient limitations (Garrison et al. 2000), partly because nutrients are recycled in a forest stand quite efficiently and dependence of trees on soil nutrient supply can be weak, particularly when it is compared with agricultural crop production.

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Mead, D.J. 1984. Diagnosis of nutrient deficiencies in plantations. In: Bowen, G.D., and E.K.S. Nambiar (eds) Nutrition of Plantation Forests. Academic Press.

Mugasha, A.G., Pluth, D.J., and Macdonald, S.E. 1999. Effects of fertilization on seasonal patterns of foliar mass and nutrients of tamarack and black spruce on undrained and drained minerotrophic peatland sites. For. Ecol. Manage. 116: 13-31.

Timmer, V.R., and Munson, A.D. 1991. Site-specific growth and nutrition of planted Picea mariana in the Ontario Clay Belt. IV. Nitrogen loading response. Can. J. For. Res. 21: 1058-1065.

Walworth, J.L., and Sumner, M.E. 1987. The diagnosis and recommendation integrated system (DRIS). Adv. Soil Sci., 6: 149-188.

Indicator: Soil nutrients

Scientific Rationale

Soil nutrient concentrations or contents are potentially the most direct measure of potential nutrient availabilities in the soil for plant primary production. However, because of the dynamics of nutrient concentrations or contents of available nutrients over time, soil nutrient concentrations measured at any one time is likely a poor predictor of plant growth. As such, when and how often to perform the measurement are all very complex issues to be answered in order for the measurements to provide meaningful results. One of the most useful measures of the soil nutrient indicator would be the net N mineralization rate, which has been found to be closely related to primary productivity (Tan et al. 2006; Carlyle and Nambiar 2001; Powers 1980). Net N mineralization rates represent the quantity of nutrients that can become available over a period of one year.

Another problem associated with using soil nutrient concentration as an indicator is its large spatial variability. A large number of samples are often required in order to gain a good understanding of the true soil nutrient status. See discussion below about spatial variability.

While the total soil nutrient content is usually poorly related to plant growth rates, it does represent the total pool of nutrients that are potentially available for plant uptake, if mineralized or released as inorganic nutrients. Thus assessing the changes in the pool size of total soil nutrients may still provide a good measure of the effects of disturbance or reclamation success.

Constrained/Unconstrained

I would propose that this indicator be classified as a constrained indicator. The measures proposed for this indicator are all operationally feasible. However, there is a lack of clarity in many of the methods involved in measuring soil nutrient availability (timing in the growing season and in a rotation of a forest stand, and lack of consistent or reliable extraction methods). Even the net N mineralization rates can be measured by a diverse array of methods and results obtained by those different methods (e.g., Binkley and Hart 1989) are not very comparable. In order for the measures proposed for this indicator to be of value (to provide a reliable surrogate of ecosystem processes), the cost may be very high.

Measures and Monitoring Program

Measure	Msrmnt unit	Min/Max Values (Targets) /Expected Trends*	Information sources *Where do you get the data?*	Methodologies to determine values (including spatial assessment)	Interpretation *What do the data show?*	Frequency of data collection†	Linkages
Soil mineral N concentration	µg/g	Forest floor: 36-45 Mineral soil: 1-5.3	**Tan et al. 2006; Campbell and Gower 2000**	2 N KCl extraction and colorimetric	Close relationship with foliar N nutrition and forest productivity	Every five years	Foliar or litter N concentration
Total soil N concentration	mg/g	Forest floor: 8-29 Mineral soil: 0.6-0.8	**Tan et al. 2006; Campbell and Gower 2000; Smith et al. 1998**	Dry combustion or wet digestion and Kjeldahl	Represents the total amount of potentially available N	Every five years	Foliar or litter N concentration
Soil extractable P concentration	µg/g	0.7-1.4	**Paschke et al. 1989**	Extraction method will depend on soil pH. Colorimetric method or ICP for determining P concentration	Close relationship with foliar P nutrition and forest productivity	Every five years	Foliar or litter P concentration
Total soil P concentration	mg/g	Organic layer: 0.48-0.72 Forest floor: 1.2-1.6 Mineral soil: 0.028-0.044	**Smith et al. 1998; Lindo and Visser 2003**	Colorimetric method or ICP for determining P concentration, after wet digestion	Represents the total amount of potentially available N	Every five years	Foliar or litter P concentration
Net N mineralization rate	µg/g/day	Mineral soil: 0.17-0.22	**Campbell and Gower 2000**	Various methods for determining net N mineralization rates	Close relationship with foliar N nutrition and forest productivity	Every five years	Foliar or litter N concentration
Net P mineralization	µg/g/day	Lab incubation: -0.5-3.3	**Lindo and Visser**	Similar to net N	Close relationship with foliar P nutrition and	Every five years	Foliar or litter P

rate			**2003**	mineralization methods	forest productivity		concentrati on
Greenhouse bioassay	Depend-ing on the analysis	NA‡	**e.g., Fyles et al. 1990**	Depending on the objective	Depending on the objective; plant N uptake in bioassay correlated with N mineralization	NA	Dependin g on the objective

*: Min/max values for soil nutrients are site-type specific

†: Sampling intensity is expected to be multiple times per season and on five-year intervals for long-term monitoring of reclamation success.

‡: Not applicable

Plus information on:

- Variability – spatial and temporal variability considerations
- Documentation of where single use of an indicator would be considered inappropriate.

Variability: spatial variability of soil nutrient measures is expected to be very large due to the large variability of the soil itself. This would require a relatively large number of samples to be collected from plots set up to monitor the progress of reclamation in the oil sands. The best approach is certainly to perform preliminary investigation to find the variability of the site and then based on the variability to perform statistical analysis to determine the minimum number of samples that need to be collected in order to achieve the desired power of statistical test.

Temporal variability of this indicator is also expected to be large. The temporal variability is caused by changes in climatic conditions, composition of the minor vegetation and tree species, natural disturbance events, and so on. Seasonal variation of soil nutrient availability will largely be influenced by changes in soil temperature and moisture conditions, and plant/microbial competition or demand for nutrients.

Single use: Single use of this indicator for measuring the success of reclamation in the oil sands should be avoided, because of the large spatial and temporal variability, and the lack of standard methods to measure most of the measures listed in the table. Even though net N mineralization rates have been reported to be related with primary productivity in forest ecosystems (Powers 1980;), contradictory results have been reported about relationships between net N mineralization rates and forest productivity, for example, net N mineralization rates have been found to be poorly related to forest productivity (Smethurst and Nambiar 1990).

Reference Cited

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Carlyle, J.C., and Nambiar, E.K.S. 2001. Relationship between net nitrogen mineralization, properties of the forest floor and mineral soil, and wood production in *Pinus radiata* plantations. Can. J. For. Res. 31: 889-898.

Fyles, J.W., Fyles, I.H., and Feller, M.C. 1990. Comparison of nitrogen mineralization in forest floor materials using aerobic and anaerobic incubations and bioassay techniques. Can. J. Soil Sci. 70: 73-81.

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Smith, C.K., Munson, A.D., and Coyea, M.R. 1998. Nitrogen and phosphorus release from humus and mineral soil under black spruce forests in central Quebec. Soil Biol. Biochem. 30: 1491-1500.

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Indicator: Soil drainage

Scientific Rationale

Soil drainage affects a soil's moisture regime and will also have an impact on the soil's ability to function, such as nutrient cycling and material translocation (Ceplecha et al. 2004), the plant's ability to function, such as water and nutrient uptake, as well as many other soil properties (Tan et al. 2004). As such, soil drainage conditions can affect plant species composition and vegetation development (Weiskittel and Hix 2003). Soil drainage conditions can also have a dramatic effect on the management of forested sites (Miwa et al. 2004). To the degree that soil drainage can have such a profound impact on nutrient cycling, soil water availability, and soil development, soil drainage would be a very important indicator of ecosystem function. Returning soil drainage to a condition comparable to that before disturbance would be a good practice to ensure the success of reclamation.

Constrained/Unconstrained

Even though soil drainage classes or conditions have mostly been assessed qualitatively, this indicator should be used as a constrained indicator. At the drainage class level, this indicator is operationally easy to assess. Sampling clarity could be improved by designing protocols that can be locally trained and applied. Cost of acquiring this indicator can be relatively low as no laboratory analysis is required for assessing this indicator. Field assessment of drainage conditions can be done rapidly. Different methods are available to assess soil drainage conditions. Distinctions are made between surface (external) drainage that is controlled by the landscape position in relation to streams and drainage ways and internal soil drainage which is affected by both landscape position (level of groundwater and seepage) and soil texture (affects permeability). A method described in the Ontario Institute of Pedology field manual (Anonymous 1985) and the Pre-harvest Ecological Assessment Handbook (Alberta Environment 2000) has been commonly used to assess internal soil drainage in the field.

Measures and Monitoring Program

Measure	Msrmnt unit	Min/Max Values (Targets) /Expected	Information sources *Where do you get the*	Methodologies to	Interpretation *What do the data show?*	Frequency of data	Linkages

		Trends*	*data?*	determine values (including spatial assessment)		collection†	
			*: This table does not apply to this indicator				

Plus information on:

- Variability – spatial and temporal variability considerations
- Documentation of where single use of an indicator would be considered inappropriate.

Variability: spatial variability is expected; however, since soil drainage class is generally a qualitative indicator, spatial variability can be better controlled by selecting and mapping sites with similar landscape position and soil textural classes.

Reference Cited

Anonymous. 1985. Field Manual for Describing Soils. Third Edition. Ontario Institute of Pedology and University of Guelph. OIP Publication number 85-3.

Alberta Environment. 2000. Pre-harvest Ecological Assessment Handbook. Environmental Training Centre, Alberta Environment. Version 2.1. 36 p.

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Tan, Z.X., Lal, R., Smeck, N.E., Calhoun, F.G., Slater, B.K., Parkinson, B., and Gehring, R.M. 2004. Taxonomic and geographic distribution of soil organic carbon pools in Ohio. Soil Science Society of America Journal 68: 1896-1904.

Weiskittel, A.R., and Hix, D.M. 2003. Canopy gap characteristics of an oak-beech-maple old-growth forest in northeastern Ohio. Ohio J. Science 103: 111-115.

Appendix 4

Indicator: Soil Salinity
Constrained

Scientific Rationale

Post-mining oilsands residues including composite (consolidated) tailings (CT) retain a high water content and high concentrations of sodium, chloride, and sulfate (Renault et al., 1998). Excess concentrations of saline and sodic materials in soils and soil-like materials are known to have toxic effects on crop growth, and Renault et al (1999) and Franklin (2002) indicated that some oilsands reclamation species (jack pine, trembling aspen) demonstrated growth inhibition and injury when treated with CT waters. Naeth (2003) summarized the results of 40 years' research on the oilsands and indicated that salinity and moisture were the two greatest limitations on plant germination and growth. The degree to which growth media or groundwater seepage waters are influenced by salinity on CT sites will likely have a significant effect on reclamation success, and there is little point investing time, plant materials and money on areas that will be too saline to support desired native boreal upland and non-saline wetland communities. Because salinity is a *determinant* of reclamation success, changes in the nature and extent of salinity and sodicity over time are concomitant *indicators* of reclamation success.

Syncrude (unpublished) has conducted geophysical surveys of mine cells in the Mildred Lake area to determine the extent of CT tailings water seepage. The purpose was to develop a means of cost-effective reliable methods of investigating the magnitude and change of salinity over time over relatively large areas. Electromagnetic surface surveys and electrical resistivity tomography cross sections to 10m depths were conducted over two separate years along fixed transects; they found locally significant changes in surface and subsurface salinity through this comparison, and concluded that geophysically-based repeated measures studies would be a useful tool for documenting and evaluating salinity changes.

References:

Franklin, J.A. 2002. The Effects of Sodium Chloride, Sodium Sulfate, and Consolidated Tailings Water on Jack Pine (*Pinus banksiana* Lamb.) Seedlings. PhD. thesis, Department of Renewable Resources, University of Alberta.

Naeth, A. 2003. Can we reclaim oilsands disturbances? Speakers' notes, CONRAD/OSERN Symposium, 2003, Edmonton.

Renault, S., Lait, C., Zwiazek, J.J. MacKinnon, M.D. 1998. Effect of high salinity tailings waters produced from gypsum treatment of oil sands tailings on plants of the boreal forest. Environmental Pollution 102: 177-184.

Renault, S., Paton, E., Nilsson, G., Zwiazek, J.J., MacKinnon, M.D. 1999. Responses of boreal plants to high salinity oil sands tailings water. Journal of Environmental Quality. 1999. v. 28 (6) p. 1957-1962.

Measurement and Monitoring Program

Measure	Msrmnt unit	Min/Max Values (Targets) /Expected Trends	Information sources *Where do you get the data?*	Methodologies to determine values (including spatial assessment)	Interpretation *What do the data show?*	Frequency of data collection	Linkages
Conductivity	mS/M	Maximum 4dS/M @ 25^{o}C [1]	**Field studies and lab samples, observations of plant growth, subjective surface assessments, photographs along *fixed points* on *established transects* over *defined intervals*.**	Constrained: Marked transects across representative post-mine reconstruction areas, data collection at established points (geophysical, soil samples to validate/add to geophysical, observations of plant growth (vigor, reproductive capability, necrosis), surface deposits of salts (subjective assessment or simple field samples), digital photographs at fixed points for qualitative assessments. Unconstrained: Plant tissue analyses to determine toxicity effects, further soil-environment studies to determine influence of other factors (e.g. soil aeration) on salinity, further work on boreal species salinity tolerances.	Transect data over time provide a spatial and temporal picture of changes in salinity that may affect reclamation success. An increase in the total area and/or the degree of salinity is a negative indicator.	Every 3 to five years initially to assess the rate of change; possibly more frequently if there are marked differences in annual precipitation to determine the possible short-term effects of precipitation-induced leaching and surface flow.	Unconstrained indicators link to constrained ones through correlation of lab or field-determined tolerance limits and observed salinity i.e. what plants are limited by and possibly what stages of growth are most critical.
Exchangeable sodium	Sodium absorption ratio	SAR maximum 15 [1]					
Alkalinity	pH	Maximum less than about 8.5					

1. Alberta Environment. 2000. Glossary of reclamation and remediation terms used in Alberta, 6th Edition. Report # EDS/LM/00-3. Pub No. T/533. 64 pages.

Spatial/temporal variability considerations: A database that facilitates tracking change through time on different treatment types is needed – materials are bound to change (e.g. CT technology will probably advance). However, it is likely that present-day CT deposits will need continued monitoring for some time to assess changes in groundwater seepage quantity and quality.

Indicator: Soil Erosion
Constrained

Scientific Rationale

Accelerated soil erosion (that which occurs at a rate exceeding normal erosion due to human or other disturbances) indicates that current site treatments are either failing to control or are exacerbating the loss of soil nutrients and organic matter from a reclaimed area. Such site instability will inhibit the re-establishment of ecosystem functions that operate on normally stable boreal sites. Erosion control is one of the primary objectives of reclamation programs (Oil Sands Vegetation Reclamation Committee 1998). The presence or absence of accelerated erosion as a result of human activities is one indicator of the probability that normal ecosystem function can be attained over time.

References:

Oil Sands Vegetation Reclamation Committee. 1998. Guidelines for reclamation to forest vegetation in the Alberta oil sands region. Alberta Environment, Edmonton. Report # ESD/LM/99-1. 212 pages

Measurement and Monitoring Program

Measure	Msrmnt unit	Min/Max Values (Targets) /Expected Trends	Information sources *Where do you get the data?*	Methodologies to determine values (including spatial assessment)	Interpretation *What do the data show?*	Frequency of data collection	Linkages
Plant cover	Foliar cover - ocular estimate	Sufficient plant cover to prevent accelerated soil erosion	**Fixed transects and sampling points on representative post-mine landscapes**	Quadrat or belt transect sampling at marked and posted intervals; benchmark on similar site type in undisturbed area.	Plant cover information can be correlated with observed presence or absence of accelerated erosion	1-5 year intervals, possibly seasonal (spring, summer)	
Litter cover	Thickness measurements	Sufficient litter cover (extent, thickness) to prevent accelerated soil erosion	**As for plant cover**	Measurements of litter thickness and cover at marked and posted intervals; benchmark on similar site type in undisturbed area.	Litter cover information can be correlated with observed presence or absence of accelerated erosion	1-5 year intervals	
Soil creep, slumping	Visual evidence, measured	No more erosion than normally experienced in vegetated natural landscapes on similar sites	**Profile and slope measurements, soil sampling locations on reclaimed**	Erosion pins, painted-rock lines and other sediment movement tracers to measure creep; visual evidence and measurements (slumping); photographic documentation and GPS location of observed erosion; assess severity depending on aerial extent; benchmark on similar site type in undisturbed area.[1]	Rate and magnitude of soil movement due to creep or slumping on reclaimed landscapes compared to benchmark	1-5 year intervals	

Sheet, rill or gully erosion, and wind erosion	Visual evidence, measured	No more erosion than normally experienced in vegetated natural landscapes on similar sites	**landforms**	Erosion pins to measure loss or deposition, repeated measures of water and sediment deposited in collection troughs at various slope positions on hills; photographic documentation and GPS location of observed erosion; assess severity depending on aerial extent; benchmark on similar site type in undisturbed area.[1]	Rate and magnitude of soil movement due to accelerated rill, sheet, gully or wind erosion on reclaimed landscapes compared to benchmark.	1-5 year intervals	

1. Rates of soil erosion can be estimated using erosion-prediction equations such as the Universal Soil Loss Equation.

Spatial/temporal variability considerations: Erosion is irregularly distributed in time and space, and selection of representative sites is a subjective process

<u>Indicator: Wetland biotic composition</u>

Unconstrained/ constrained (see discussion)

Scientific Rationale

"Consideration of the design and requirements of wetlands must be an integral part of mine planning and design, as well as mine closure planning… The ultimate objective is to provide sustainable, biologically diverse and productive wetlands in the reclaimed landscape" (Alberta Environment 2000).

"Performance assessment goals, as well as reclamation guidelines and criteria, must be established to assess the physical, chemical and biological characteristics of wetlands established on reclaimed landscapes. These assessments are needed to determine whether a wetland is meeting its intended function (e.g., flood control, water treatment, habitat) and whether it is "free-to-evolve."…. Criteria for assessing the performance and success of wetland reclamation must be site specific, measurable and based on a clear understanding of the functions to be provided." (Oil Sands Wetland Working Group 2000).

These two quotes indicate the requirement for wetlands as a part of reclamation planning; the second statement also speaks to the need for measuring the degree to which an intended function is being met. Input water chemistry can have an important impact upon wetland development and function and may be a valuable indicator of wetland ecosystem health. However, input chemistry is a consequence of and reflects the health of nearby upland ecosystems. For example, dissolved nitrogen (in the form of nitrate) is often considered an indicator of high nitrogen availability in dryland systems (a positive indicator). This is also, however, an important mechanism of nitrogen loss from those ecosystems through leaching as well as a mechanism of eutrophication in wetland ecosystems.

References:

Alberta Environment. 2000. Guideline for wetland establishment on reclaimed oil sands leases. Conservation and Reclamation information letter. C&R/IL/00-2. 4 pages.

Leonhardt, C. 2003. Zoobenthic succession in constructed wetlands of the Fort McMurray Oil Sands Region. In: J. Ciborowski. 2003**.** Zoobenthic Community Development and Function in Wetlands of the Alberta Oil Sands: Current Knowledge and Next Steps. Speakers' notes, CONRAD/OSERN Symposium, 2003, Edmonton.

Oil Sands Wetlands Working Group (OSWWG). 2000. Guideline for Wetland Establishment on Reclaimed Oil Sands Leases. Neil Chymko (Editor) Report # ESD/LM/00-1. Alberta Environment, Environmental Services. Publication No. T/517.

Measurement and Monitoring Program

Measure	Msrmnt unit	Min/Max Values (Targets) /Expected Trends	Information sources *Where do you get the data?*	Methodologies to determine values (including spatial assessment)	Interpretation *What do the data show?*	Frequency of data collection	Linkages
Physical and chemical properties of input water to wetlands	Water and substrate chemistry (cations, anions, pH, temperature, organics), flow rates	Standards are available from Provincial toxicity guidelines but may be modified as wetlands develop. Should be generated in collaboration with wetland working group.	Water and substrate sampling where plot data are collected, inflow rates. Data collected for wetland characterization purposes.	Standard field and laboratory test methods for water sampling.	Provide chemical information that might be correlated with nutrient availability and nutrient loss from upland ecosystems	5 year intervals	Soil nutrients

Spatial/temporal variability considerations: Seasonal changes, changes in process water inputs and outputs, wetland variability induced by differences in materials and fluid throughput, or groundwater inputs, or materials deflation and dewatering.

Indicator: Plant species diversity index
Constrained

Scientific Rationale

A primary criterion for reclamation success, according to the Oil Sands Vegetation Reclamation Committee (1998) and the Oil Sands Wetlands Working Group (2000), is the re-establishment.of natural biodiversity by reclaiming post-mining landscapes to communities that are similar to native communities in composition and structure. Because native communities are themselves inherently variable, numerous indices have been developed to facilitate rapid comparisons between communities using readily obtained community statistics; these reduce structural (usually cover or biomass) and compositional (species richness) information to a single number. Indices that identify significant differences (i.e. that incorporate both composition and structural attributes) provide a more objective means of comparing communities than indices based on one or the other attribute (Strong 2002).

An appropriate index of species diversity that reflects both species composition and occurrence calculated for both reclaimed communities and their natural analogues occurring under similar moisture-nutrient conditions (e.g. "ecosite phases") would provide a means of quickly comparing the similarity between reclaimed and native communities. If community composition and structure reflect ecosystem function, indices would provide some indication of the degree to which ecosystem function is comparable between reclaimed and native communities.

Plant species diversity indices should not be used as the sole criterion for making decisions as to whether reclaimed and native communities are functionally similar. Reclaimed communities composed entirely of undesirable weedy or exotic species could be just as diverse as communities composed entirely of native species and could have very similar indices; however, for various reasons (see discussion on invasives indicator) such diversity is undesirable from a reclamation standpoint. It is also important to compare communities that are found on similar sites if the objective is to assess ecosystem function. It would be incorrect to equate diversity indices for native communities on very dry sites (e.g. vascular species-poor jackpine stands on sand) to native communities on moist sites (e.g. aspen communities on lacustrine materials), and equally incorrect to compare diversity indices between reclaimed landscapes and native landscapes on different sites.

References:

Oil Sands Vegetation Reclamation Committee. 1998. Guidelines for reclamation to forest vegetation in the Alberta oil sands region. Alberta Environment, Edmonton. Report # ESD/LM/99-1. 212 pages

Oil Sands Wetlands Working Group (OSWWG). 2000. Guideline for Wetland Establishment on Reclaimed Oil Sands Leases. Neil Chymko (Editor) Report # ESD/LM/00-1. Alberta Environment, Environmental Services. Publication No. T/517.

Strong, W.L. 2002. Assessing species abundance unevenness within and between plant communities. Community Ecology 3(2): 237-246.

Measurement and Monitoring Program

Measure	Msrmnt unit	Min/Max Values (Targets) /Expected Trends	Information sources *Where do you get the data?*	Methodologies to determine values (including spatial assessment)	Interpretation *What do the data show?*	Frequency of data collection	Linkages
Diversity index	Depends on the index chosen (usually unitless measures reflecting the aggregate of information comprising the index)	Target: similar index values for reclaimed and native communities of approximately the same age class	**Plot samples (collect species presence and abundance information)**	Use existing plot data or establish new plots; organize by site type and reclamation material category(e.g., (moist-rich, dry-poor, average) on tailings sand, CT deposits, etc. Calculate indices (e.g. dominance concentration index (Strong 2002) and compare to indices calculated from plot data on similar site types, collected using sufficiently similar techniques to allow a valid comparison.	Comparable index values, when taken together with a review of actual species occurring at reclaimed and native sites, indicate similar communities and probably similar ecological functional states.	Every five years for the first 20 years; thereafter, every 10 years.	Invasive species assessments.

Spatial/temporal variability considerations:
Should not be considered independently from the invasive species indicator; it is possible to have a highly diverse community of undesirable species.

Indicator: Invasive plant species
Constrained

Scientific Rationale

Invasive plant species may be considered as either “favorable” (native species that displace introduced agronomic species or other native species) or “unfavorable” (aggressive exotic species or weeds that displace desired species or retard succession toward native communities). References to native plant invasion are frequent throughout the Oil Sands Vegetation Reclamation Committee (1998) and Oil Sands Wetlands Working Group (2000) reports; a focus of the reclamation program is to “encourage the invasion by native vegetation and establish woody seedlings” (Oil Sands Vegetation Reclamation Committee (1998)).

“Invasive plant species” could therefore be considered an indicator of reclamation success if native species successfully invade post-mine sites and re-establish ecological function. They could also be considered an indication of reclamation failure if weedy or exotic species take over and prevent succession to native communities and/or create further problems on-site or off-site (e.g. escaping into stream drainages and spreading along major rivers).

References:

Oil Sands Vegetation Reclamation Committee. 1998. Guidelines for reclamation to forest vegetation in the Alberta oil sands region. Alberta Environment, Edmonton. Report # ESD/LM/99-1. 212 pages

Oil Sands Wetlands Working Group (OSWWG). 2000. Guideline for Wetland Establishment on Reclaimed Oil Sands Leases. Neil Chymko (Editor) Report # ESD/LM/00-1. Alberta Environment, Environmental Services. Publication No. T/517.

Measurement and Monitoring Program

Measure	Msrmnt unit	Min/Max Values (Targets) /Expected Trends	Information sources *Where do you get the data?*	Methodologies to determine values (including spatial assessment)	Interpretation *What do the data show?*	Frequency of data collection	Linkages
Invasive species presence and abundance	List of species presence and abundance	Targets vary by category: *Desirable native invaders*: occurrence and abundance similar to target natural plant community *Restricted, noxious or nuisance weeds:* Target is no occurrence. *Exotic species:* Target depends on reclamation objective; eventual target is no occurrence for those species that might be come problems (e.g.	**Plot samples (collect species presence and abundance information)** **Digital photographic documentation especially of undesirable legislatively controlled weedy species.**	Ocular assessments of species composition and cover in plots. Documentation (population estimates, digital photographs, GPS locations) for undesirable plants and particularly for noxious, restricted or nuisance weeds.	Successional trends in plant communities (native species) Presence of, and trends in, populations of undesirable plant species	Every five years for the first 20 years; thereafter, every 10 years. (native species) Continuous monitoring (restricted, noxious, or nuisance weeds and exotic species that may be considered problem plants.)	

		smooth brome, crested wheatgrass					