Best Management Practices

For Conservation of Reclamation Materials in the Mineable Oil Sands Region of Alberta

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PREFACE

The Best Management Practices Task Group (BMPTG) under the direction of the Terrestrial Subgroup (TSG) and the Reclamation Working Group (RWG) of the Cumulative Environmental Management Association (CEMA) was formed to identify and record Best Management Practices (BMPs) or guidelines for soil salvage and placement in the mineable oil sands area.

The rationale and context for the development of the BMPTG and subsequent documents resulted from the 2006 Energy Resources Conservation Board (ERCB) (formerly known as the Alberta Energy and Utilities Board (EUB)) public hearings for three oil sands mine applications. It was the Government of Alberta's (GOA) position that "through adaptive management, [reclamation] practice will be improved over time with implementation of Best Management Practices," (GOA submission to the EUB for Imperial Oil Limited's Kearl Oil Sands Project – see Energy Resources Conservation Board 2007 section 12.1.9 for Alberta's position on soil management). It is from this GOA direction that Alberta Environment and Water (AEW) and Alberta Sustainable Resource Development (ASRD) requested and received approval from CEMA, an appropriate multi-stakeholder forum, to advance the development of BMPs for soil salvage and placement in the mineable oil sands region.

The GOA began to implement new conditions for soil/reclamation material salvage and placement in recently updated (2007) *Environmental Protection and Enhancement Act* (EPEA) approvals. These new conditions are quite different from previous soil salvage and placement requirements, and the BMPs provide the opportunity for further assessment and operational review of these new conditions. However, it should be noted that at this time, it is not the role of the BMPs to supplant or replace EPEA approval conditions.

The key objective of the BMPTG was to conduct a review of historical and current BMPs for soil salvage and placement to capture existing knowledge and experience with a focus on upland reclamation. A second objective is to work with operators that are currently implementing the new conservation and reclamation requirements to develop new BMPs to describe emerging practices that are becoming apparent through the implementation of these requirements.

This is a living document assembled to represent current and best understanding of techniques to reclaim oil sands mines, with all of the complexities of biological systems and their functions as an overlay, and with the expectation that good environmental outcomes can be achieved. The BMPs provide a discussion of leading practices without precluding innovation and experimentation leading to continuous improvement.

The document was developed with the intention of providing leading practices that will help operators optimize the use of available reclamation materials on a site-specific basis. EPEA approvals state that operators should consider any guidelines prepared or provided by the Director related to the development of soil salvage and placement strategies. In this context, the BMPs will inform the development of the annual Soil Salvage and Placement Plans, the Mine Reclamation Plan and the Life of Mine Closure Plan – the BMPs are not intended to be used as evaluation criteria for appraising any particular operator.

The BMPs are provided as background to aid operators with current and planned reclamation activities to enable continuous improvement. BMPs provide a reasonable level of guidance on practice for activities representing moderate risk and are based on imperfect knowledge. When using this document it is important to think about interactions between individual BMPs, as well as the BMPs and external factors. The following examples are intended to provide further clarification.

What Is The Target?

Generally the target for mine reclamation can be stated as a 'self-sustaining, locally common boreal forest.' However in a more specific sense, closure planning is attempting to steward to ecosite phases, which are defined as groupings of forest ecosystems defined by similarity in inherent soil moisture and nutrient characteristics and the associated vegetation cover. This level is quite specific and results in a unique context for each reclamation area. For example, reclaiming a site that has the potential to support large numbers of terrestrial lichens may mean utilizing soil-cover designs which are not ideal for tree productivity. Many of the BMPs in this document need to be considered and interpreted with the target in mind.

What Is Optimal?

Designing a soil cover that results in the ideal outcome for a given polygon may not lead to the best landscape outcome. Consider a simple case where there are two options: place deep layers of native soil on 10 hectares, and place minimal soil depths on 10 hectares; or, place a moderate depth on all 20 hectares.

Which Is Best?

The two options above are different and need to be considered in totality and not in isolation. For mines, an applicable concept is life of mine material balances weighed against today's reclamation programs. Optimization considered over large areas and time frames is liable to lead to better results than decisions made annually and without consideration of spatial and temporal aspects of planning for the closure landscape. A further useful consideration for these BMPs is that some mines are nearing maturity and material balances may not have sufficient soil to provide for specific soil-cover designs; newer mines or greenfield projects will not face the same constraints.

Optimization may also be considered as contingent to some degree on landform or landscape factors. Consider the following: lower and toe slope positions in the native forest are generally associated with increases in soil moisture and nutrients. It may, therefore, be tempting to take high quality soil materials and place them on these positions. However, if the basic landform is created with saline/sodic overburden, these toe slope positions may represent high risk for salt intrusions, and considered optimally, may suggest use of less valuable soil materials.

What about Operational Feasibility and Cost Benefit?

It is understood that operational constraints may not allow all BMPs to be achieved. Each BMP has management implications and many of the BMPs possess adaptive management concepts. Management implications are factors that may limit the implementation of a BMP; however, they may also be factors that necessitate implementation of a BMP. The adaptive management concepts are suggestions or techniques that can be applied to help implement the BMPs.

Some adaptive management concepts have limited operational practice behind them to understand the overall benefits as well as the costs of implementation. The benefit to the final landscape may have been inferred rather than based on direct observation of operational practice. From this perspective, it is valid to keep in mind the relationship between the potential benefit and the cost associated with it. Some of these practices may not have a cost increase associated with them (relative to current practice); however, many of these BMPs do cost more to implement.

The document discusses techniques to ensure (1) that live soil materials representing a propagule source are available after lengthy stockpiling and (2) the optimal use of fresh forest floor materials. These techniques are important in achieving end land-use goals but have not been proven through consistent operational practice. The intent is to provide avenues of future practice to be tested for operational feasibility and this general approach represents a cornerstone of adaptive management.

What about Interactions Between Specific BMPs?

Some of these BMPs overlap to some extent. Best management practices that relate to stockpiling have strong linkages to soil salvage and placement activities. There could also be inconsistencies in some cases (i.e., implementing a BMP for soil placement may contradict a BMP concerned with stockpiling). Throughout the document the linkages to relevant and related BMPs have been provided to allow the user to consider the related BMPs as a complete package.

The BMPs have been presented in this document as individual fact sheets. While this leads to some content repetition, this approach makes it easier for users to understand how the different BMPs link with each other and how consideration of one BMP affects the consideration of another.

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SUMMARY OF BMPs

#	BMP	RATIONALE
PRE-DISTURBANCE DATA COLLECTION		
1	Collect pre-disturbance data when planning tree clearing and soil salvage operations	One of the purposes of collecting pre-disturbance data is to characterize the available resources for planning timber salvage, seed collection, woody debris and soil salvage operations. Gaining an understanding of the pre-disturbance site conditions is essential to confirm that operators are taking appropriate steps to preserve soil and vegetation resources for use later in reclamation, and thus, stewarding towards achieving better environmental outcomes and overall reclamation objectives.
SEED COLLECTION		
2	Collect native seeds within the Athabasca Oil Sands Region	Local seed is an important reclamation material because these plant species are generally better adapted to local climate conditions. Using seeds that are collected from pre-mined areas for revegetation programs is intended to conserve the genetic diversity that existed prior to disturbance.
WOODY DEBRIS		
3	Use woody debris as a reclamation material	Woody debris (WD) is a valuable reclamation material that provides several benefits. These benefits include: (1) the creation of microsites which increase germination and emergence of in situ propagules and seeds/spores; (2) the creation of localized changes in soil moisture; (3) a habitat for small animals and soil fauna; (4) the addition of organic matter and release of nutrients to soil via vegetation decay; and (5) erosion control.
UPLAND SURFACE SOIL SALVAGE		
4	Salvage upland surface soil from all land to be disturbed	Upland surface soil is the most valuable reclamation material available for use as coversoil. It provides an important and unique source of organic matter, plant nutrients and woody debris. If directly placed, it also provides seeds, plant propagules and soil biota. Using it again as coversoil is a low-risk strategy, given that it developed under and supported boreal forest vegetation prior to disturbance. Because of the limited extent of upland versus wetland prior to disturbance, most of the post-disturbance landscape will be reclaimed using peat-mineral mix as coversoil. For this reason, surface soil should be salvaged from the full extent of uplands on the pre-disturbance landscape to maximize the volume available.

#	BMP	RATIONALE
TRANSITIONAL SOIL SALVAGE		
5	Salvage transitional soils	The biological and nutrient capital of transitional soils makes it a valuable reclamation material. The identification of transitional soils is based upon several beneficial properties including but not limited to: (1) a high level of biodiversity contained within the soil and plant communities; (2) an abundant and diverse representation of soil organisms; (3) a diverse representation of vascular and non-vascular propagules; (4) soil macroinvertebrate and meso/micro fauna; (5) good organic matter and mineral mix ratio quality; and (6) a rich source of soil nutrients. Transitional ecosystems have distinct vegetation and soil characteristics resulting from their landscape position and these ecotones provide multiple benefits and help create and preserve healthy aquatic ecosystems. Salvaging transitional soils is one method that can be used to transfer the benefits from pre-mined areas back onto reclaimed landscapes.
PEAT-MINERAL MIX		
6	Salvage organic soils	Organic soil is an important reclamation material used widely as a coversoil material in the Athabasca Oil Sands Region (AOSR) and makes up the volumes required for coversoil when volumes of upland surface soil are limited. Adding mineral soil to peat to create a peat-mineral mix improves the tilth and reduces the risk of losing organic matter due to rapid decomposition or in the event of a surface fire. Peat-mineral mixes created either during salvage, stockpile or placement help improve the success of reclaiming post-disturbance upland landscapes and are also an abundant source of organic matter that can be salvaged cost-effectively.
7	Avoid incorporating peat with unsuitable underlying mineral soil	Incorporating unsuitable mineral soil with peat to create a peat-mineral mix reduces the quality of the peat and also creates conditions unfavourable for plant growth.
SUBSOIL AND OVERBURDEN SALVAGE		
8	Salvage subsoil and suitable overburden	Subsoil and suitable overburden are valuable reclamation materials. Once placed on a post-disturbance landscape, they provide plants with: (1) a rooting zone that stores nutrients and water; (2) a medium for anchorage; and (3) a barrier between roots and the potentially harmful elements or compounds that may be present in the underlying overburden or tailings sand. Subsoil and suitable overburden play a major role in closure reclamation soil cover designs. The quality of subsoil and suitable overburden salvaged influences the time frame and management effort required to create self-sustaining boreal forest plant communities. Salvage of subsoil and suitable overburden to meet regulatory requirements is intended to achieve reclamation objectives. The soil regulatory requirements, spatial scale and soil quality variability of the materials in the undisturbed landscape

#	BMP	RATIONALE
		influence the soil salvage techniques. With adequate pre-disturbance information to characterize subsoil and overburden quality, assuming quality is suitable, subsoil and suitable overburden can be combined during salvage. In the absence of information to characterize overburden quality, discrete salvage of subsoil materials or reduced salvage depths may be required to minimize admixing of unsuitable overburden with subsoil for reclamation.
SEGREGATION OF RECLAMATION MATERIAL		
9	Segregate coarse-textured upland soils from fine-textured upland soils	Soil texture and structure significantly affect the water and nutrient dynamics of a soil. The texture of a soil will not change during salvage, storage or placement activities unless soils with different textures are mixed together (as soil particle-size distributions are produced through physical and chemical weathering processes that are operative over far longer time frames than those occurring in the oil sands mining disturbance – reclamation cycle; Brady and Weil 2002). A synthesis of oil sands mine reclamation research has shown that soil structure is not adversely affected by winter soil-handling operations, and that “reclaimed soils exhibit soil physical properties not significantly different from similar textured soils in undisturbed areas” (Barbour et al. 2007). This same synthesis identifies use of different soil textures as a key mechanism in determining post-reclamation ecological characteristics: “Ecosites developed on coarse-textured soils (a/b ecosites) have poorer nutrient regimes and drier moisture regimes than those of ecosites developed on fine-textured soils (d ecosites). Soil capping practices suitable for achieving these various ecosites should be designed accordingly.” Because of the influence of soil texture and structure on moisture retention, and because these properties can be maintained through the soil handling cycle, segregating coarse-textured soil from fine-textured soil for both upland surface soil and B-horizon subsoil will help preserve each soil’s capability for reclaiming different site types and diverse ecosystems. The spatial scale and variability of how soils with different textures are naturally segregated needs to be considered prior to segregating different soil textures.
STOCKPILING		
10	Segregate stockpiles by reclamation material type	Reclamation materials differ in particle size, organic matter content and nutrients. The inherent value of selectively stockpiling reclamation material based on texture and fertility is a major factor affecting water and nutrient dynamics of a reconstructed soil.

#	BMP	RATIONALE
11	Integrate reclamation material stockpile locations into the mine planning process	The locations of stockpiles, for all types of reclamation material, need to be considered so that the full range of reclamation materials is available when placement areas are available. Integrating stockpile location and design into the mine planning process should ensure that stockpiles are not moved during the life of mine except for reclamation purposes. Stockpile locations should be situated close to future placement areas to minimize costs of transporting reclamation materials.
12	Stockpile upland surface soil at well-drained locations	Stockpiling upland surface soil on well drained areas helps preserve soil quality.
13	Salvage upland surface soil at stockpile locations that are not designated as upland surface soil stockpiles	Upland surface soil is a valuable reclamation material and must be conserved.
14	Use suitable overburden materials to create access roads or to pad peat and peat-mineral stockpiles or in situ peat areas	Peat and peat-mineral mix are valuable reclamation materials. Mixing unsuitable overburden with peat or peat-mineral mix reduces the quality of the reclamation material.
15	Construct geotechnically stable, non-erosive stockpiles and control weeds as per relevant regulations	Stockpiling is essential to successful mine planning and reclamation. Properly constructed stockpiles can help maintain soil quality on and off-site by preventing stockpiled soil from eroding. Various methods can be used to maintain a viable propagule bank of locally common boreal plant species. Controlling weeds prevents the spread of unwanted plant species.
16	Document stockpile properties	Numerous stockpiles of various reclamation material types can result from life of mine salvage operations. Properly identifying stockpiles is critical to ensure the properties of the stockpiled reclamation materials are documented and to ensure the stockpiles are not mistakenly used or degraded during mine operations. Documenting the locations, properties and management methods of each stockpile is necessary for effective materials handling, mine reclamation planning and for determining reclamation material balances.
DIRECT PLACEMENT		
17	Direct placement is preferred to stockpiling	Direct placement of reclamation materials is preferred to stockpiling because soil quality and structure is better maintained and reclamation costs are reduced. Direct placement of upland surface soil and transitional soil is preferred because seed viability, nutrients, organic matter and soil biota are difficult to replenish or require additional measures once degradation occurs in stockpiles. Direct placement of upland surface soils, transitional soil and the surface of organic soils ensures that viable propagules are preserved and available for revegetation. Direct placement of peat-mineral mix and subsoil should be done when feasible.

#	BMP	RATIONALE
SOIL PLACEMENT		
18	Identify constraints associated with the landscape when planning soil-cover designs	The three main constraints that determine the land capability to support boreal ecosystems in the AOSR are Soil Moisture regime (SMR), Soil Nutrient Regime (SNR) and salinity. Understanding these constraints enables operators to: (1) develop soil-cover designs that achieve reclamation objectives; (2) prioritize the placement of upland surface soil, transitional soil and subsoil on areas that will prevent degradation of the soil quality of these reclamation materials; and (3) select reclamation materials and placement areas to achieve target ecosites / site types.
19	Use appropriate reclamation material to meet objectives	A soil-cover design should provide a soil cover that can support a self-sustaining ecosystem. A soil-cover design needs to supply plants and soil biota with nutrients, water and a hospitable environment for growth. Some factors that influence the availability and storage of nutrients and water are the type of substrate used to construct a landform, the reclamation material, the plant community and the landscape position. These factors also influence the movement of potentially harmful substances from substrates into the rooting zone. The types of reclamation materials used and the order in which they are placed within soil-cover designs will depend on reclamation objectives and the target plant community to be revegetated. Salvaged reclamation materials used in soil-cover designs include: upland surface soil (coarse and fine); transitional soil; peat; peat-mineral mix; subsoil (coarse and fine); and suitable overburden.
20	Place an adequate depth of material to separate coversoils from substrates of marginal soil quality	A minimum depth of material is required over substrates with marginal soil quality to create a buffer between unsuitable material and suitable material. This helps to support plant growth and achieve reclamation objectives.
21	Place a sufficient depth of reclamation material to support a rooting zone and tree cover and to achieve reclamation objectives	A sufficient depth of reclamation material is needed to provide support for roots and sufficient storage of water and nutrients to sustain boreal forest plant communities.
SOIL QUALITY DEGRADATION		
22	Preserve soil quality to meet reclamation objectives	Timber harvest, clear and grub, peatland drainage and soil salvage/placement operations can negatively affect the chemical and physical properties of soil if the environmental conditions and equipment used are unsuitable.
POST-PLACEMENT SITE PREPARATION		
23	Leave coversoil rough on the surface	Rough surfaces (0.1 to 0.5 m microtopographic relief) provide: (1) microsites that enhance native seed/spore catch, increase germination and emergence of in situ propagules, and create localized changes in soil and moisture regime; (2) habitat for small animals and soil fauna; and (3) erosion control.

#	BMP	RATIONALE
24	Use fertilizer applications specific to reclamation objectives for a site	Inappropriate use of fertilizer can be detrimental to desirable plant species; therefore, fertilizer applications should be site-specific and based on soil and/or plant tissue analysis. Applying fertilizer before, or recently after, soil placement or planting of woody species often promotes the establishment weeds and a plant community dominated by herbaceous plants. Weeds and herbaceous plants can outcompete planted trees and shrubs and prevent ingress of desired locally common boreal species.

GLOSSARY

Bituminous Hydrocarbons – the heavy viscous hydrocarbon associated with the Athabasca Oil Sands deposits.

Cleared – areas where vegetation has been removed for the purposes of preparing the land for drainage, soil removal, overburden removal, mining, but where soil has been left intact and relatively undisturbed.

Clear and Grub – removing trees, brush and other woody debris from a site before soil salvage. Clear and grub operations may involve raking slash and non-merchantable timber into piles, which are later burned.

Closure Plan – a long-term conceptual planning document that extends to the end of mine life, outlining the technical measures and planning programs to be undertaken for the decommissioning, remediation, and reclamation of a mine and plant site, with the ultimate goal of reclamation certification and return of land to the Crown[1]. Referred to as the Life of Mine Closure Plan in EPEA approvals.

Constraint – the state of restricting, limiting, or regulating the physical, chemical and/or biological functions of life outside of normal growth conditions, such that, soil quality and plant growth is reduced. Elevated levels of salinity and sodicity are examples of constraints.

Coversoil – any of the following: peat-mineral mix; organic horizon; upland surface soil or transitional soil.

Direct Placement – a combined salvage and placement operation wherein coversoil is moved directly from the area of salvage to the area of placement.

Disturbed – areas where soil has been removed or covered by other materials. This category includes all areas where soil removal, overburden removal, active mining, discard placement, materials storage, etc. have occurred.

Donor Site – the site from which soils, plant parts, or other reclamation materials are salvaged prior to anthropogenic disturbance.

Ecosite – a functional unit defined by the soil moisture regime and soil nutrient regime. Ecosites have a unique recurring combination of vegetation, soil,

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[1] The majority of lands are Crown however there are small parcels of private land. On the private land parcels the land would be returned to the landowner.

landform, and other environmental components. Ecosites are different in their soil moisture and soil nutrient regimes.

Ecosystem – a complex of living organisms and their environment, linked by energy flows and material cycling.

Ecotone – a region of transition between two biological communities.

Effective Rooting Depth – the upper portion of the root zone where plants get most of their water. Effective root depth is estimated as one-half the maximum rooting depth.

End Land-Use – the planned use for each reclamation unit after mine closure, which is not necessarily the same as its predevelopment use. Examples include: traditional use, commercial forestry, recreation, grazing, agriculture and industrial use[2].

Equivalent Land Capability – 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. The individual land uses may be different than the predevelopment use.

Forest Floor – a layer of dead organic matter and living organisms on the surface of the mineral soil in a forest, the mass of which consists largely of dead plant parts in various stages of decomposition. It usually consists of one or more organic horizon (LFH) as defined in the Canadian System of Soil Classification, 3rd Edition, 1998, as amended (Soil Classification Working Group 1998).

In situ – in the ground, undisturbed or in its original place.

Inspection Density – the amount of ground truth (digs or observations) required in a soil survey. An "observation" or "dig" can be defined as a ground truth that the pedologist can use as a control point to extrapolate the mapping.

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[2] See the Oil Sands Mining End Land Use Committee: Report and Recommendations available at http://environment.gov.ab.ca/info/posting.asp?assetid=6856&searchtype=asset&txtsearch=end land use

LFH – an organic horizon containing > 17% organic C (approximately ≥ 30% organic matter) by weight. It is developed primarily from the accumulation of leaves, twigs, and woody materials with or without a minor component of mosses. It is also normally associated with upland forested soils with imperfect drainage or drier.

> L: this organic horizon is characterized by an accumulation of organic matter in which the original structures are easily discernible.
>
> F: this organic horizon is characterized by an accumulation of partly decomposed organic matter. Some of the original structures are difficult to recognize. The material may be partly comminuted (pulverized) by soil fauna as in moder (a non-matted forest humus), or it may be a partly decomposed mat permeated by fungal hyphae as in mor.
>
> H: this organic horizon is characterized by an accumulation of decomposed organic matter in which the original structures are indiscernible. This horizon differs from the F by having greater humification due chiefly to the action of organisms. It is frequently intermixed with mineral grains, especially near the junction with mineral horizons.

Land Capability – the ability of the land to support a given land use, based on an evaluation of the physical, chemical and biological characteristics of the land, including topography, drainage, hydrology, soils and vegetation.

Landforms – the various shapes of the land surface resulting from a variety of actions such as natural deposition or sedimentation (eskers, lacustrine basins), erosion (gullies, canyons) and earth crust movements (mountains); or engineered construction and contouring.

Landscape – the composite of all visible features including land, water and vegetation, and its interacting ecosystems.

Lean Oil Sand – ore that does not meet the cut off grade of 7 weight percent bitumen. Lean oil sand is the minimum bitumen content of the Oil Sands that would be classified as ore by the Energy Resources Conservation Board.

Lowland – land that is saturated with water long enough to promote wetland or aquatic processes, indicated by poorly drained soil and hydrophilic vegetation.

Mine Plan – Energy Resources Conservation Board reviewed and approved annual plan.

Mine Reclamation Plan (MRP) – the detailed operational plan for development and reclamation over a 10-year period. A Mine Reclamation Plan is typically updated every three years. The MRP is reflective of the Life of Mine Closure

Plan, with considerations for changes to the Mine Plan. The MRP provides detailed plans and procedures that support reclamation to an equivalent land capability.

Mineral Soil – soils containing low levels of organic matter. Soils that have evolved on fluvial, glaciofluvial, lacustrine and morainal parent material. It may include one or more of the following mineral horizons A, B or C horizon as defined in the Canadian System of Soil Classification, 3rd Edition, 1998, as amended (Soil Classification Working Group 1998).

Mulch – any material such as straw, sawdust, woodchips, leaves or loose soil that is spread on the soil surface to protect the soil and plant roots from the effects of raindrops, wind erosion, soil crusting, freezing and evaporation.

Non-Merchantable Timber – trees that have a diameter of 10 cm or less measured at a height of 1.3 metres.

Organic Soil – an order of soils that have developed dominantly from organic deposits. The majority of organic soils are saturated for most of the year, unless artificially drained, but some of them are not usually saturated for more than a few days. Organic soils contain more than 17% organic carbon by weight.

Operations – all activities at a mine prior to mine closure, which might include construction, ore extraction and product processing.

Overburden – material below the soil profile and above the bituminous sand.

Parent Material – the unconsolidated and more or less chemically weathered mineral or organic matter from which pedogenic processes develop the solum of a soil.

Peat – material constituting peatlands, exclusive of the live plant cover, consisting largely of organic residues accumulated as a result of incomplete decomposition of dead plant constituents under conditions of excessive moisture (submergence in water and/or waterlogging).

Peat-Mineral Mix – a mixture of an organic horizon and one of the following:

- underlying mineral material;
- subsoil from another location; or
- overburden that meets the criteria of good or fair as subsoil according to Table 4, Page 56 of the *Alberta Tier 1 Soil and Groundwater Remediation Guidelines*, Alberta Environment, February 2009, as amended.

Permanent Reclamation Activities – activities that support permanent reclamation such as: landform construction and contouring, clean material placement (as required), reclamation material placement and vegetation planting have occurred which is reflective of the approved revegetation plan.

Planning – a detailed design of mining activities leading to the Mine Plan development, as well as short-term and long-term reclamation planning leading to development of the Mine Reclamation Plan and Life of Mine Closure Plan.

Post-Mined Landscape – a landscape formed after mining operations have occurred.

Propagule – a structure with the capacity to give rise to a new plant. For example: a seed, a spore or a part of the vegetative body capable of independent growth if detached from the parent.

Reclamation Material – any type of soil, suitable mineral and/or organic material that can be used to improve the physical, chemical, and biological properties of the substrate or soil used for reclamation. Reclamation material can also include woody debris, roots and seed cones.

Reclamation Material Balance – the estimated volumes of each of the various types of reclamation materials required to achieve the reclamation objectives for the site calculated with consideration for short-term and long-term needs for soil salvage, storage, and placement.

Reclaimed Land (or Areas) – vegetated, disturbed areas with the land capability returned to a status at least equivalent to predevelopment, with or without reclamation certification granted.

Risk – exposure to a constraint, characterized by probability of occurrence and severity of consequence.

Site Type – an ecological classification unit broader than ecosite.

Slope – the percentage of vertical rise relative to horizontal distance. A level site has a percent slope of zero degrees, and 45 degrees is equivalent to 100% slope.

Soil – the naturally occurring, unconsolidated mineral or organic material at least 10 cm thick that occurs at the earth’s surface and is capable of supporting plant growth.

Soil Horizon – a layer of mineral or organic soil material approximately parallel to the land surface that has characteristics altered by processes of soil formation. A soil mineral horizon is a horizon with 17% or less total organic carbon by weight. A soil organic horizon is a horizon with more than 17% organic carbon by weight.

Soil Inspection – either intrusive or non-intrusive methods of characterizing the physical and chemical components of the soil.

Soil Quality – the capacity of soil to function within a specific kind of ecosystem in a manner that sustains plant and animal productivity, maintains or enhances water and air quality, and supports human health and habitation.

A measure of the condition of soil relative to the requirements of one or more species and/or any human need or purpose.

A basic, intrinsic characteristic of a soil that is a reflection of several soil properties and cannot be directly characterized in one measurement, ordinarily estimated from a number of measurements and/or observations.

Soil Survey – a general term for the systematic examination of soils in the field and in the laboratory, their description and classification, the mapping of kinds of soil, and the interpretation of soils for many uses, including their suitability or limitations for growing various crops, grasses and trees, or for various engineering uses and predicting their behaviour under different management systems.

Solum – the upper horizons of a soil in which the parent material has been modified and in which most plant roots are contained. It usually consists of the A- and B-horizons as defined in the Canadian System of Soil Classification, 3rd Edition, 1998, as amended (Soil Classification Working Group 1998).

Stockpile – reclamation material salvaged and stored for future use.

Subsoil – a stratum that includes one or more of the following as defined in the Canadian System of Soil Classification, 3rd Edition, 1998, as amended (Soil Classification Working Group 1998): (1) that portion of the B horizon left after salvage of upland surface soil; (2) the C horizon of an upland soil; and (3) the C horizon of an organic soil (e.g., Terric layer).

Substrate – the material that underlies the reclamation material cap. Typical substrates include cretaceous Clearwater formation, cretaceous McMurray formation (oil sand), and tailings sand. Substrates may also include subsoil, peat-mineral mix, suitable overburden, coke and sulphur.

Suitability – the appropriateness of a site to support a proposed activity or attribute; usually a relative scale is used to gauge suitability such as high, moderate, low, or not suitable.

Survey Intensity Level – the number of field inspections per unit area or other estimates of accuracy.

Temporary Reclamation – areas where cover soils may have been placed and vegetation has been seeded, planted or ingressed; however, further disturbance is expected at that location. This does not include cleared areas that have revegetated naturally.

Transitional Soil – mineral soils developed on mineral material under forest in locations with imperfect drainage or wetter, typically including an organic horizon over a mineral horizon.

Upland – land that is dry long enough to promote upland forest processes, indicated by imperfect to rapidly drained soil and non-hydrophilic vegetation.

Upland Soil – means soils developed on mineral parent material under forest in locations with imperfect drainage or drier, typically including LFH and A, B, and C horizons.

Upland Surface Soil – a stratum salvaged from an upland soil that includes the forest floor, A horizon and in some cases part or all of the B horizon.

Unsuitable Reclamation Material – mineral material that is determined to be not suitable for reclamation use. Information on suitability may be provided by guidance documents (e.g., the Alberta Soil Quality Criteria – Alberta Soils Advisory Committee 1987) or on site-specific soil characterization, for evaluation of parameters such as salt content, pH, hydrocarbon or $CaC0_3$-content. It should be recognized that Soil Quality Criteria (SQC) provide generic ratings which may not be applicable to material available at a lease level or to specific reclamation objectives (e.g., reclaiming ecosites based on coarse-textured soils).

Wetland – land characterized by open water or a rooting zone that is wet for long enough periods that native aquatic or semi-aquatic vegetation is present (e.g., riparian, marsh, fen and bog).

Windrow – any similar row of reclamation materials.

Woody Debris – sound and rotting logs and stumps that provide habitat for plants, animals and insects and a source of nutrients for soil development. The material is generally greater than 8 to 10 cm in diameter. Includes trees/branches that have died and remain standing or leaning.

LIST OF ACRONYMS AND ABBREVIATIONS

Acronym or Abbreviation	Definition
AEW	Alberta Environment and Water
AOSR	Athabasca Oil Sands Region
ASRD	Alberta Sustainable Resource Development
AVI	Alberta Vegetation Inventory
BMP(s)	Best Management Practice(s)
BMPTG	Best Management Practices Task Group
CEC	Cation exchange capacity
CEMA	Cumulative Environmental Management Association
CONRAD	Canadian Oil Sands Network for Research and Development
EC	Electrical conductivity
EIA	Environmental Impact Assessment
EPEA	*Environmental Protection and Enhancement Act*
ERCB	Energy Resources Conservation Board
ERRG	Environmental Reclamation Research Group
EUB	Alberta Energy and Utilities Board
FMA	Forest Management Agreement
GPR	Ground penetrating radar
LCCS	*Land Capability Classification System for Forest Ecosystems in the Oil Sands* (Alberta Environment 2006)
LFH	Litter, fibric, humic
LIDAR	Light detection and ranging
LOS	Lean oil sand
MRP	Mine Reclamation Plan
PGM	Parent geologic material
PHC	Petroleum hydrocarbons
QA/QC	Quality assurance/quality control
Revegetation Manual	*Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region* (Alberta Environment 2010)
RWG	Reclamation Working Group
SAR	Sodium adsorption ratio
SMR	Soil moisture regime
SNR	Soil nutrient regime
SQC	*Soil Quality Criteria Relative to Disturbance and Reclamation* (Alberta Soils Advisory Committee 1987)
TNC	Total nonstructural carbohydrate

Acronym or Abbreviation	Definition
TSG	Terrestrial Subgroup
WD	Woody debris
Wetlands Manual	*Guideline for Wetland Establishment on Reclaimed Oil Sand Leases* (Alberta Environment 2008)

INTRODUCTION

This document provides a summary of best management practices (BMPs) for soil salvage and placement in the mineable oil sands area in the Regional Municipality of Wood Buffalo. Developed by the Best Management Practices Task Group (BMPTG)[3], it reflects current operational practices, monitoring and research. This document was designed to provide technical information to reclamation specialists as well as less specialized professionals from industry, government and non-governmental organizations.

The goal of this publication is to identify and document leading soil salvage, storage and placement procedures for oil sands mine reclamation. Reclamation of mines is a complex undertaking and involves disciplines and activities far beyond the scope of this document. Where appropriate, references and additional resources are provided; however, consultation with trained professionals (e.g., soil scientists, foresters, agrologists, biologists, engineers, geologists and hydrogeologists) will be required for detailed reclamation design.

What Are Best Management Practices?

Best management practices are approaches based on knowledge or operational procedures that, if implemented effectively, increase the chances of meeting the long-term conservation and reclamation goals. Best management practices also identify where improvement is needed, by articulating limitations and knowledge gaps.

The BMPs are based on existing knowledge and supported by evidence-based research, monitoring, professional knowledge (including operational experience, company experience and individual professional experience), theoretical principles and field-tested outcomes. They target the establishment of a self-sustaining, locally common boreal forest.

The BMPs included in this document are not defining new standards, and they do not replace the *Environmental Protection and Enhancement Act* (EPEA) approval conditions. They are not meant to prescribe procedures for reclamation and restoration. Instead, the techniques and guidance in this document should be understood as the best reclamation practices presently known to CEMA. When planning a mine reclamation project, users are encouraged to assess the various practices and to seek additional sources of expertise and knowledge to complement the information provided here.

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[3] BMPTG is a task group of the Terrestrial Subgroup (TSG), under the Reclamation Working Group (RWG), which is part of the Cumulative Environmental Management Association (CEMA).

Why Are Best Management Practices Needed?

These BMPs are designed to help industry stakeholders target the establishment of a self-sustaining, locally common boreal forest, to achieve the environmental outcomes specified in EPEA approvals, using available reclamation resources to produce the best possible outcomes. In addition, the process of documenting BMPs helps to identify information gaps to CEMA and the Canadian Oil Sands Network for Research and Development (CONRAD) Environmental and Reclamation Research Group (ERRG). This process also provides a forum to share information with government, industry and other stakeholders.

Who Are Best Management Practices For?

Best management practices help industry stakeholders develop more efficient plans to steward towards achieving better environmental outcomes and overall reclamation objectives. Best management practices provide information, guidance and common understanding among industry, government, aboriginal people, other stakeholders, and the general public. Industry practitioners and government regulators are encouraged to consult the BMPs when designing or reviewing reclamation plans. The users of this document may chose a number of techniques to incorporate the BMPs into the operational practices of an organization. These techniques may include the development of Standard Operating Procedures (SOPs), the implementation of training courses for field supervisors and operators, or field trials to demonstrate the application of the BMPs in an operational context. Each organization must assess the best overall strategy needed to take the BMPs from the current document into operational practice.

Best Management Practices and Existing Oil Sands Guidance Documents

Other guidance documents provide information about achieving target land capabilities, plant communities and wetlands on reclaimed areas; however, these documents do not address specific soil salvage and placement practices to achieve desired outcomes. The information and guidance provided in this document is not intended to replace guidance provided in other oil sands guidance documents such as the *Land Capability Classification System for Forest Ecosystems in the Oil Sands* (LCCS; Alberta Environment 2006), *Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region* (Revegetation Manual; Alberta Environment 2010) and *Guideline for Wetland Establishment on Reclaimed Oil Sand Leases* (Wetlands Manual; Alberta Environment 2008). Rather, this document describes practices that will help achieve specific goals set out in each of the guidance documents.

Updating the Best Management Practices

Conservation and reclamation techniques for oil sands mining projects will continue to evolve and improve over time. Thus it is critical that the techniques outlined in this document are revisited as new practices and technologies emerge. This document will be reviewed every five years or when considerable advancements in knowledge have been made. Operational knowledge, experience and research results obtained through CEMA, CONRAD and other initiatives will continue to be incorporated into the BMPs.

Use of the Best Management Practices in Reclamation Planning

A progressive reclamation plan considers annual soil salvage and placement plans through to Life of Mine Closure Plans to minimize environmental impacts of the mining project. An important consideration in life of mine closure planning is the end land-use. End land-use is determined by the sustainability and land capability of the post-mining landscape; as well as input from resource managers, industry, members of the surrounding communities and government. The sustainability of a diverse end land-use network is greatly influenced by the selective handling of soil and overburden materials to retain properties essential for sustaining plant growth and achieving the reclamation materials balance.

Key components of a reclamation plan include:

- Comprehensive characterization of soils, overburden and substrates (i.e., coke, sulphur blocks, tailings) to achieve a reclamation materials balance relative to life of mine requirements.
- Selective handling of soil and overburden to create a satisfactory root zone for plants and to protect water resources.
- Consideration of the temporal availability and spatial location of categories of reclamation material within the mine footprint.
- Integration of landforms, topography, vegetation, water bodies and watercourses with undisturbed areas within or adjacent to the mine areas and with adjacent operators that support a range of end land-uses.
- Appropriate soil-cover designs that meet end land-use targets.
- Construction of a post-mine landscape that is geotechnically stable against wind and water erosion to ensure sustainability of the defined end land-use and protect water resources.
- Incorporation of micro- and mesotopography on landforms.
- Consideration of the surface water hydrology and groundwater hydrology and hydrogeology.
- Consideration of the spatial and temporal scale of the operations.
- Assessment and monitoring activities to measure reclamation performance.

A planning system that defines and tracks reclamation material inventories and salvage, storage and placement activities enables operators to incorporate BMPs into their reclamation operations. The BMPs are one of several guidance documents that have been developed to help achieve reclamation objectives through structured planning. Operators are to consider any guidelines prepared or provided by the Director related to soil salvage and placement strategies within their Annual Soil Salvage and Placement Plans, Mine Reclamation Plans and Life of Mine Closure Plans.

Best Management Practice Structure

The BMPs are presented in an order that follows mining and reclamation operations. The document is structured to follow common activities from the pre-disturbance stage to post-placement site preparation. Each BMP is presented as a fact sheet comprised of the following six sections:

- The rationale for implementing the BMP;
- Current practices used by operators;
- State of knowledge pertaining to the BMP;
- Management implications that can limit the implementation of the BMP;
- Adaptive management concepts, which are suggestions or techniques that can be used to help implement the BMP; and
- Knowledge gaps that identify where current scientific or operational knowledge is lacking with respect to that BMP.

PRE-DISTURBANCE DATA COLLECTION

BMP 1 Collect pre-disturbance data when planning tree clearing and soil salvage operations.

Rationale

One of the purposes of collecting pre-disturbance data is to characterize the available resources for planning timber salvage, seed collection, woody debris and soil salvage operations. Gaining an understanding of the pre-disturbance site conditions is essential to confirm that operators are taking appropriate steps to preserve soil and vegetation resources for use later in reclamation, and thus, stewarding towards achieving better environmental outcomes and overall reclamation objectives.

Current Practice/Strategy:

Oil sands operators have implemented a variety of techniques for pre-disturbance data collection including a combination of map polygon models and/or field surveys. There are no specific approval or regulatory requirements for pre-disturbance data collection that oil sands operators must adopt to meet tree clearing and soil salvage objectives.

Vegetation: A variety of methods are used to meet different objectives and scales. Vegetative ecosite map polygons are used to determine the vegetation community characteristics of an area. This information is used to help develop plans for timber clearing, seed collection, woody debris, reclamation and revegetation.

Vegetation is surveyed using a combination of aerial photography, satellite imagery and ground truthing using methods that are described in the resources listed below:

- *Pre-Harvest Ecological Assessment Handbook and Forest Site Interpretation and Silviculture Prescription Guide for Alberta* (Alberta Environment 2000). These resources describe assessment methods for classifying plant communities.
- *Ecological Land Survey Site Description Manual* (Alberta Environmental Protection 1994). This resource describes field methods to characterize ecological units.

- *Field Guide to Ecosites of Northern Alberta* (Beckingham and Archibald 1996). This guide provides a classification key for ecological units based upon plant species composition and abundance, and important soil properties.
- *Alberta Vegetation Inventory Interpretation Standards Version 2.1.1. Chapter 3 – Vegetation Inventory Standards and Data Model Documents* (Alberta Sustainable Resource Development 2005a). The Alberta Vegetation Inventory (AVI) manual describes procedures for mapping the type, extent and conditions of vegetation. It relies on a spatial polygon layer with forest cover labels consisting of moisture regime, timber productivity rating, crown closure, height, and species composition, origin and stand structure.
- *The Canadian Wetland Classification System, 2nd Edition* (National Wetlands Working Group 1997). This classification system provides tools to classify wetlands into five wetland classes.
- *Alberta Wetland Inventory Standards – Version 1.0* (Halsey and Vitt 1997). This classification system provides tools to classify wetlands.
- *ANPC Guidelines For Rare Plant Surveys* (Alberta Native Plant Council 2000). This guide provides standardized assessment methods used to determine the presence of rare plant species.

Ecosite: Describing ecological units to the ecosite level is suitable for planning timber and soil salvage operations. Data collected from vegetation and soil surveys are combined to describe ecological units to the ecosite level. Ecosite classification is described in an ecological framework that incorporates the influence of soil moisture regime (SMR) and soil nutrient regime (SNR) on the composition and abundance of plant species present at any particular site. Ecosite classification provides a high level of information of the potential soil and timber resources, which can be used as an aid in mine planning activities.

Soil and Overburden: Information regarding current practices was obtained from reviews of 2009 Annual Soil Salvage and Placement Plans, as well as discussion with government and operators. The quality of data collected for reclamation material selection is dependent on survey design, survey methods and the parameters selected for characterization. Characterization of pre-disturbance soils is generally performed using a combination of modelling tools and field soil surveys. The amount and quality of soil information available varies through the course of mine development. During the initial stages of mine development the soils inventory is generally from soil and geologic surveys associated with the environmental impact assessment (EIA). These surveys are generally a high level investigation (low intensity scale survey) of the soil resources for the purpose of developing a long-range closure plan (e.g., identification of suitable/unsuitable materials for reclamation, mine material balance). As mine areas approach the point of disturbance, additional field soil surveys are conducted to verify the soil resources present and adjust soil salvage plans for short-term planning.

Survey Methods: Survey techniques depend on intrusive sampling techniques to distinguish between soil types. Results are correlated with vegetation and landscape features to extrapolate soil-mapping units. Multiple soil surveys may be conducted consecutively. Standard methods for soil surveying and mapping are described in the following documents:

- *A Soil Mapping System for Canada: Revised* (Mapping Systems Working Group 1981). This manual describes detailed procedures for mapping soils.
- *Soil Quality Criteria Relative to Disturbance and Reclamation* (SQC; Alberta Soils Advisory Committee 1987). This resource describes methods used to sample, characterize and map soils and overburden. The SQC is used to evaluate the quality of soil materials for use in reclamation.
- *Canadian System of Soil Classification* (Soil Classification Working Group 1998). This classification system provides a key for classifying soils to the Subgroup level.
- *Land Capability Classification System for Forest Ecosystems in the Oil Sands* (Alberta Environment 2006). This classification system describes detailed methods for rating land capability of forest ecosystems.

Soil Characterization: Suitable reclamation materials are characterized through analytical and field tests. Analysis of material to the depth of the oil sand resource may be conducted to characterize the suitability of the materials present for use in reclamation. The parameters generally measured are texture, salinity, sodicity, pH, presence of hydrocarbon and coarse fragment content.

The EIA process emphasizes the use of the SQC to evaluate reclamation suitability. Because of the approval requirement to salvage all upland soil, the Soil Salvage and Placement Plans focus on potential constraints (pH, electrical conductivity (EC), sodium adsorption ratio (SAR), coarse fragments and presence of hydrocarbons). The SQC has been used to identify potential constraints for reclamation. Recommendations on the suitability of reclamation material (Good, Fair, Poor and Unsuitable) are largely determined using Tables 8 and 9 from the SQC. It is important to note; however, that the SQC will not by itself determine thresholds for exclusion and in some instances the SQC may not include all applicable soil parameters when evaluating materials for reclamation. Other soil parameters may be necessary when evaluating materials for use in soil reclamation.

State of Knowledge:

Survey Design and Sampling Intensity: Survey design and sampling intensity varies when collecting data at different stages of mine development for different reclamation materials. It is critical to note that the design and sampling intensity depend on whether or not the information will be used to determine which soils to salvage, versus how to segregate reclamation material for future use.

Conventional mapping of soils based on classification and genesis is informative, although not all information gathered is relevant. More intensive grid surveys tend to focus on specific parameters that affect salvage quality.

The soil inventory information collected for the EIA is used as a guide to develop the initial soil salvage plan and reclamation material balance for the entire mine area. During the EIA, surveys are conducted at a low intensity scale and a stratified sampling regime is often used. Soil mapping at this stage is critical for developing closure plans, making long range forecasts for material balances and developing future sampling designs to characterize suitable reclamation materials.

A final soil survey is conducted prior to soil and overburden removal to provide sufficient resolution to develop Soil Salvage and Placement Plans. This provides a more accurate appraisal of the quality and quantity of salvageable upland surface soil, subsoil, peat and suitable overburden. Some operators take additional samples to increase the inspection intensity (e.g., 100 m x 100 m grid) in previously surveyed areas.

Soil Characterization: The parameters selected for determining reclamation material suitability are different among operators because soil and overburden characteristics vary within the mineable oil sands area and the end land-use varies among operators. Some known factors that affect the quality of reclamation material and therefore must be considered are listed below:

- Geologic formations and materials influenced by soil weathering processes that have a pH outside the accepted range (e.g., Calcareous material at the bottom of the soil profile (or lower) or marl present a high pH that is less than optimal for native vegetation).
- Elevated salinity and sodicity of certain geologic materials (e.g., Clearwater Formation).
- Hydrocarbons are encountered in some native soils and underlying material. Refer to Appendix A: Salvage of Reclamation Material with Indigenous Hydrocarbons for further guidance on determining the suitability of reclamation materials containing naturally occurring hydrocarbons.
- Coarse fragments are encountered in some soils developed on glaciofluvial materials.

Soil texture is a special concern. Experience with soil salvage plans and operations indicates that an SQC grade of Poor based on texture alone (e.g., clay or sand) should not be applied where other parameters rate Good or Fair. The use of native surface soils is encouraged; however, in some cases the soil may not be suitable on the basis of texture. Therefore, soils with marginal textures that are otherwise suitable are not excluded on the basis of texture.

Management Implications:

Determining an accurate estimate of suitable reclamation material for salvage can be difficult because of the variable distribution of vegetation, soil and overburden within a given area. It is considered best practice to review survey objectives and select the best tools and resources available to determine the appropriate sampling density, the parameters for analysis and the sampling design. Given the current tools used to classify and quantify available soil resources, operators need to be aware that there are cost savings associated with the modelling technique, but the field survey technique will result in more accurate data. The additional costs using field surveys could result in greater savings and improved reclamation performance for operators (Table 1).

Table 1. Relative Cost and Data Quality Comparisons of Soil Sampling Techniques

Technique	Cost (Initial)	Final Cost (Potential)	Data Quality	Reclamation Performance (Potential)
Modelling (e.g., ecosites)	↓	↑	↓	↓
Field surveys	↑	↓	↑	↑

Adaptive Management:

The level of detail used for sampling should be commensurate with how the material is handled in salvage, stockpiling and placement. When soils are heterogeneous and non-selectively handled, more detail may be required. Mixing disparate materials with the subsoil can degrade the original soil properties of the subsoil resulting in lower quality reclamation material than if the subsoil is salvaged separately. The following soil parameters need to be considered when characterizing the quality of reclamation material when subsoil is mixed with overburden: pH, coarse fragments, SAR, EC, hydrocarbons and texture. Analytical testing may not be required if subsoil on upland soils is salvaged separately from the material below the subsoil; however, analytical testing may be required if physical and chemical properties are of concern.

Analytical techniques may vary among laboratories, and operators should consider the differences in analytical techniques when evaluating data. Using consistent analytical methods may be as critical as refining soil survey methods. Using different analytical methods for characterizing soil makes it challenging to compare results among different AVI polygons, sites, projects and operators. All routine soil analysis should be done according to methods in *Soil Sampling and Methods of Analysis, Second Edition* (Carter and Gregorich 2008).

Non-intrusive survey methods could supplement intrusive methods to provide more detailed information and increase the accuracy of reclamation material estimates. Non-intrusive soil surveys use instruments to measure soil and/or physical material properties directly or indirectly. Non-intrusive methods include: ground penetrating radar (GPR), light detection and ranging technology (LIDAR), electromagnetic surveys and infrared spectroscopy. Advantages of these methods include high-resolution products, non-destructive processes, use of real-time data and increased efficiency. Some operational experience suggests that GPR methods are not sufficient for determining peat depths and that the type of peat can influence results. Further research is recommended to verify the accuracy and costs of these methods.

Consulting an experienced soil surveyor is recommended to optimize the sampling regime according to the objectives of the soil survey. Sample intensities may need to be higher than what current guidelines recommend, particularly in areas where soil properties are suspected to be more heterogeneous.

Knowledge Gaps:

The appropriate scale of survey, survey techniques (intrusive, non-intrusive, equipment), soil characterization methods (field vs. lab) and appropriate models for planning are still unknown. The following areas have been identified as needing further evaluation to help assess and characterize reclamation materials:

- LIDAR has been used extensively for forest inventories; however, its accuracy, cost and applicability for surveying reclamation materials are unknown.
- The parameters listed in Tables 8 and 9 in the SQC may not represent the overall quality of a particular reclamation material. When solum is compared to suitable overburden materials many of the parameters are of equal value; however, the tables do not include other factors (e.g., nutrients, organic matter and roots) that would otherwise identify the solum as being of greater value. The resolution of the parameters in the SQC may also require further exploration to determine the level of suitability of various types of reclamation material.
- Optimizing salvage quantity and quality may be more effective if supplemental sampling is done ex situ (e.g., in stockpiles and after placement). In situ sampling only represents the quality of material at particular depth intervals over a range of sample locations. This method may not reflect the actual volume or quality of material that is being salvaged for reclamation. Ex situ sampling needs to be assessed and compared to in situ sampling methods for

different reclamation materials, using different handling practices, to confirm that salvage practices are meeting salvage plans.

- Research is being conducted to determine the types of hydrocarbons, and the concentrations in reclamation materials that affect plant productivity. Refer to Appendix A for further details. Appropriate survey techniques and classification of suitable/unsuitable materials based on hydrocarbon content is still relatively unknown.

SEED COLLECTION

BMP 2 Collect native seeds within the Athabasca Oil Sands Region.

Rationale

Local seed is an important reclamation material because these plant species are generally better adapted to local climate conditions. Using seeds that are collected from pre-mined areas for revegetation programs is intended to conserve the genetic diversity that existed prior to disturbance.

Current Practice/Strategy:

EPEA approvals require oil sands operators to use local native plant species for reclamation. Native sources are defined as those plant species collected within the Athabasca Oil Sands Region (AOSR) within the Saskatchewan Central Mixedwood Plains (seed zones 2.1 and 2.2) and Mackay Central Mixedwood Lowlands (seed zones 2.2) (Alberta Sustainable Resource Development 2005b). Operators collect native sources either individually or within a seed cooperative.

Information about collection, processing and propagation techniques for tree species is available in *The Woody Plant Seed Manual* (Young and Young 1992) and *Seeds of Woody Plants in North America* (Bonner and Karrfalt 2008). Refer to the *Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region* (subsequently referred to as the Revegetation Manual; Alberta Environment 2010) for specific guidelines and best management practices for seed collection for some individual shrubs and herbaceous plants. Fact sheets on common seed processing, collection and propagation techniques of native plants are available in the Revegetation Manual.

State of Knowledge:

Using native sources is beneficial for conservation of genetic diversity, re-establishment of similar vegetative communities and promotion of natural soil forming processes. A disadvantage is that the variety of species commercially available is often too low to meet industry needs. Local native seed supplies are limited to a few tree, shrub and herbaceous species. Limited information is available on the effects of provenance on the fitness of shrubs and herbaceous species within and outside the AOSR. Until the effects of provenance are better understood, it is considered best practice to use local sources of native seed.

Common methods used to collect, propagate and plant for a variety of native plant species in the AOSR can be found in the Revegetation Manual.

Management Implications:

Promotion of local native plants is encouraged because of the perceived benefits; however, operators should be aware of the availability of stock to meet industry needs, specifically future needs when demand increases. Obtaining seed volumes in sufficient quantities can be difficult for various plant species and more difficult when seed collection sites are restricted to a particular seed collection zone. If insufficient shrub and herbaceous seed quantities are available in a particular seed zone then seed should be collected from the same sub-region as the area to be planted.

Image 1. Slash pile containing jack pine cones available for seed collection.

Adaptive Management:

Understanding the different mechanisms of re-establishment for target species will improve revegetation success on reclaimed lands. Operators may need to adopt a variety of techniques to re-establish different plant species. Direct placed surface soil is an excellent source of propagules for revegetation. Soil salvage practices, as a method of seed collection, are appropriate when soil is directly placed onto reclaimed areas.

Silviculture methods have used cone redistribution/scattering as a successful reforestation practice for many years. Collecting cones with viable seed and scattering them on reclaimed areas is considered an adaptive management practice. Branches in slash piles may contain an abundant supply of viable seed that can be used as a source for cone collection, incorporated into the surface soil or be added to woody debris. Tree species such as jack pine have serotinous cones which can be stored for years without losing viability. Black spruce cones are semi-serotinous and can be stored for one to five years. White spruce and tamarack do not have serotinous cones therefore viability of the seeds is reduced to one to two years. White spruce and tamarack seed production is often sporadic and viable seed is only available for use during masting years.

Knowledge Gaps:

Farming the forest floor layer is a technique that could provide additional sources of propagules for revegetation. The technique involves leaving residual seed and roots on site after the forest floor layer has been salvaged. The propagules produce new seedlings that grow and mature to develop a new soil seed and bud bank. The SMR and SNR of the site determine how quickly a new forest floor layer begins to develop. This technique has not been validated; however, it may be a viable collection and propagation system in future. Further research is needed to determine which species have a positive and negative response to this technique to establish its effectiveness. In addition, a cost-benefit analysis and the impacts on soil quality should be completed before implementing this practice on a large scale.

WOODY DEBRIS

BMP 3 Use woody debris as a reclamation material.

Rationale

Woody debris (WD) is a valuable reclamation material that provides several benefits. These benefits include:

- The creation of microsites which increase germination and emergence of in situ propagules and seeds/spores;
- The creation of localized changes in soil moisture;
- A habitat for small animals and soil fauna;
- The addition of organic matter and release of nutrients to soil via vegetation decay; and
- Erosion control.

Current Practice/Strategy:

Prior to soil salvage, standing trees and WD are managed through a series of timber salvage and clear and grub operations. Methods used in timber harvest and clear and grub operations will determine the availability and distribution of WD. The timing and methods of these operations impact the viability of plant root systems and the soil quality when WD is placed on reclamation areas.

For timber salvage, merchantable timber is harvested and moved off site. Timber salvage typically occurs during fall and winter months and may occur several years before soils are salvaged. Timber salvage operations are required to follow the *Migratory Birds Convention Act* (Government of Canada 1994), which prohibits the destruction of nests of migratory birds during timber salvage operations. Migratory bird surveys are completed prior to timber salvage. The local forest officers are consulted for specific guidelines for timber salvage operations. Additional regulations are provided in the *Forest and Prairie Protection Act* (Government of Alberta 2007b).

Clear and grub operations prepare the surface for soil salvage. Slash and non-merchantable timber is raked into piles and burned. Smaller pieces of WD are left on the surface. Some operators mulch slash and non-merchantable timber into coarse mulched material or coarse wood chips to minimize smoke production. Stumps and roots (grubbing) may be removed, especially if scrapers will be used to salvage soil and subsoil. Refer to *Directive 2009-01 Management of Wood*

Chips on Public Land (Government of Alberta 2009) for additional direction on how to manage wood chips and other types of WD on public land.

Image 2. Pre-mined, clear and grubbed soil salvage area on an a/b ecosite. Coarse woody debris has been pushed into slash piles.

State of Knowledge:

Ecological Benefits: The ecological benefits of adding WD back onto surfaces of newly created landscapes include: creating additional habitat for wildlife, plants and fungi; providing erosion control; contributing to long-term soil organic matter; aiding in nutrient cycling; and increasing plant productivity (Harmon et al. 1986; Freedman et al. 1996; Stevens 1997; Pyle and Brown 1999; Raija and Prescott 2004; Debeljak 2006). In addition to improving seed catch of native plants, WD can improve soil quality by forming microsites for microorganisms and mesofauna that are important in nutrient cycling. It may also help severely degraded land regain ecological function by aiding and quickening the recovery of mesofauna, microorganisms, soil nutrients, soil water and plant diversity (Brown 2010).

WD Use in Reclamation: Applying WD on reclaimed mine landscapes is a restoration/reclamation technique used on other mines throughout the world (Norman et al. 1997; Mansourian et al. 2005; Koch 2007). Woody debris is used for controlling erosion and providing habitat. Additionally, WD can reduce browsing and vehicle traffic. The use of WD on reclaimed lands within the AOSR is limited; however, Brown (2010) determined that the application of WD on reclaimed landscapes was beneficial because it increased species richness and decreased introduced species cover. Brown (2010) also determined that woody plant abundance was positively associated with woody debris cover. Application of WD resulted in some nitrogen immobilization and phosphorous leaching; however, the extent was not determined.

The abundance and size of WD added to reclaimed landscapes or into the soil during salvage determines its effectiveness for reclamation. Directive 2009-01 (Government of Alberta 2009) describes the negative and positive impacts of wood chips and coarse WD in reclamation. The majority of the literature describes the effects of WD from top application but not from the aspect of incorporating into the soil. Although there is no definitive threshold limit for what constitutes too much WD in soil, it is understood there is a critical value where increased WD can negatively impact soil quality by nutrient retention caused by WD decay.

Woody debris is added as a bulking agent to enhance aerobic respiration (a major driver in the compost process) in various types of compost piles (Hoitink and Fahy 1986). Increasing the amount of WD to be stored with soil would likely increase the risk of composting soil and possibly increase the risk of fire. On areas where woody plant establishment is not recommended, or where access is required, WD may not be recommended.

Material Balance Requirements: When using WD, operators should target 10% to 20% maximum ground cover, which is within the range of most boreal ecosystems (Brown 2010). See Pedlar et al. (2002) for a description of coarse woody debris volumes for various types of disturbances and forest types in the boreal forest. Determining a schedule of availability of woody debris during planning will help determine volume requirements and placement strategies.

Management Implications:

Appropriate management of WD depends on site-specific reclamation objectives. Various options are available for managing woody debris. The following strategies are listed in order of preference for use in reclamation:

(1) placement on reclamation areas to create habitat, and enhance plant establishment and biodiversity;
(2) erosion control;
(3) stockpile for future use;
(4) coarse mulch; and
(5) burning.

Operators must be aware that each option has a different impact on operations, soil quality, propagule viability and WD availability.

Mulching all WD into coarse mulch is considered a better practice than burning or mulching into fine mulch. Burning WD may be appropriate when there are still excessive amounts left after placement and storage or if there are insufficient placement and storage areas.

The amount of WD required for placement on reclaimed areas should equal the desired amount of WD targeted for placement minus the existing WD left on the surface after coversoil placement. It is expected that most upland surface soils contain an abundant supply of WD. Under normal timber harvesting and clear and grub operations, direct placement of upland surface soil often results in 5% to 8% ground cover of WD after placement (MacKenzie 2006, 2011). Incorporating excess amounts of WD enhances composting process and excessive WD mixed with upland surface soil results in an undesirable soil medium that is difficult to re-spread. This may result in poor soil-to-seed/root contact. There is no definitive guideline on the volume that causes negative impacts to upland surface soil; however, a maximum threshold of 10% to 20% is recommended at this time. Refer to Directive 2009-01 (Government of Alberta 2009) for more detailed direction on management of wood chips. For peat-mineral mixes, there is typically less than 1% WD on the ground after placement (MacKenzie 2006, 2011; Brown 2010).

Determining a schedule of WD availability for reclamation involves both long-term and near-term estimates. The time frame for WD estimates may be more appropriate for the near-term when reclaimed areas are or will be available soon for WD placement. Long-term estimates will be required to show that WD is available when needed. However, storing WD over the long-term may not be possible due to space limitations. WD storage locations should be selected in areas that reduce the risk of fire (e.g., within the mine). Forest officers should be consulted to determine the storage location and time frame to reduce the risk of fire.

Image 3. Slash pile burning.
This is not considered a best practice.

Timber harvest and clear and grub operations should minimize the amount of forest floor that is included in slash piles by leaving roots and stumps in the soil. Viable seeds and roots are most abundant within the forest floor layer and the forest floor contains the majority of nutrients and organic matter. Removing this layer from reclamation material substantially reduces the total amount of propagules, nutrients and organic matter. Leaving a larger portion of WD on the ground will reduce the amount of forest floor lost to slash piles. Additionally, clear and grub operations conducted when soils are frozen help maintain intact forest floor layers.

From an operations perspective, there are a number of challenges in obtaining woody debris. Some examples include: EPEA approvals that require all merchantable timber to be salvaged; fire hazards posed by storing or piling WD;

challenges loading and moving WD safely to the reclamation site (e.g., loading WD is hard to do safely with standard mining equipment because the broken ends of the trees frequently damage equipment and create a risk of injury to the operators).

Image 4. Thick layer of coarse mulch overlying upland surface soil. This is preferable to mulching fine.

Image 5. Thick layer of fine mulch overlying upland surface soil. This is not a recommended practice.

Adaptive Management:

When WD volumes are inadequate to meet reclamation objectives, merchantable timber may be used. The Forest Management Agreement (FMA) holder and appropriate government representatives should be consulted to determine if merchantable timber can be retained on site for use as WD if the volumes of non-merchantable WD are insufficient for reclamation. Forest officers should be consulted to determine the storage locations and time frame to reduce the risk of fire. Frequent infrared scans can also be implemented to reduce risk of fire. Appropriate safety measures (e.g., brush guards) can be taken to reduce injury to equipment and workers when handling WD.

To avoid peat fires, slash/brush piles should be burned on upland areas. Slash/brush piles can also be burned safely on mineral soil. To help conserve propagule viability and preserve soil quality, upland surface soil under slash piles should be removed prior to burning. High intensity burns on the forest floor will kill the majority of propagules within the forest floor and within the upper Ae horizon. Burn scars left after burning slash piles can be deleterious to the chemical and physical characteristics of upland surface soil.

Knowledge Gaps:

Using WD on reclaimed areas in the AOSR is a recent practice. As such, best practices for handling this material are still being developed. The knowledge gaps identified by the BMPTG are:

- Young and mid-seral forests have a more abundant and diverse propagule bank than late seral forests (Moore and Wein 1977; Warr et al. 1993). Harvesting old growth forests years in advance of soil salvage increases the total soil propagule bank; however, the time interval between harvesting and soil salvage (for the purpose of increasing the regeneration success for aspen) needs to be further researched. In addition, a cost-benefit analysis should be completed.
- Wounding aspen roots can increase the amount of suckering (Fraser et al. 2004). Using silvicultural practices such as disking or ripping prior to soil salvage can increase the abundance of regenerating aspen suckers on undisturbed soils; however, the effects of these practices have not been studied when soil is directly placed on reclaimed areas.
- WD is beneficial when applied on reclamation areas, but the maximum and minimum application rates required to optimize erosion control, nutrient balances, habitat creation and species establishment are unknown. In addition, the effects of the various class sizes and tree species (for each of the above factors) need to be assessed.

- Decay rates of WD have been determined in natural forest ecosystems; however, decay rates of WD incorporated into the soil, left in soil stockpiles or left in WD stockpiles are not well researched.
- WD can be incorporated into the forest floor during salvage or placed on the forest floor after soil placement. The difference between these practices on erosion control, nutrient balance, habitat creation and species establishment is unknown. The maximum volume of WD that can be incorporated into forest floor without reducing the overall soil quality and/or effectiveness of seed and root propagation also needs to be determined.
- The possibility of creating WD through thinning practices on mature reclaimed areas could be investigated.

Image 6. Woody debris on a post-mined landscape used for reclamation.

UPLAND SURFACE SOIL SALVAGE

BMP 4 Salvage upland surface soil from all land to be disturbed.

Rationale

Upland surface soil is the most valuable reclamation material available for use as coversoil. It provides an important and unique source of organic matter, plant nutrients and woody debris. If directly placed, it also provides seeds, plant propagules and soil biota. Using it again as coversoil is a low-risk strategy, given that it developed under and supported boreal forest vegetation prior to disturbance. Because of the limited extent of upland versus wetland prior to disturbance, most of the post-disturbance landscape will be reclaimed using peat-mineral mix as coversoil. For this reason, surface soil should be salvaged from the full extent of uplands on the pre-disturbance landscape to maximize the volume available.

Current Practice/Strategy:

The majority of EPEA approvals require salvage of upland surface soil from all land to be disturbed. The approval requirements are similar to conventional oil and gas wellsite reclamation techniques for forested zones of Alberta (Government of Alberta 2007a); however, salvage depth is dependent on ecosites and soil texture. Coarse-textured soils, typically associated with a/b ecosites, are salvaged to a maximum depth of 15 cm. Fine-textured soils, typically found on ecosites other than a/b, are salvaged to a maximum depth of 30 cm. Varying salvage depth based on texture or ecosite takes into account the variable depth of the forest floor layer (i.e., LFH) in these soils. Coarse-textured soils (a/b ecosite) generally have a thinner organic surface horizon relative to fine-textured soils.

State of Knowledge:

General: The importance of salvaging upland surface soil in the AOSR has been recognized; however, in the past, both perceived and real logistics and cost prevented its use as a reclamation material on a large scale (Ziemkiewicz et al. 1980). Research in the AOSR has demonstrated the value of upland surface soil as an abundant and diverse source of viable propagules to post-disturbance landscapes (MacKenzie 2006, 2011). Operators now recognize this soil resource and segregate this soil during salvage for use as reclamation coversoil. The literature pertaining to upland surface soil used for reclamation in the boreal forest is limited to studies done mostly within the AOSR (Lanoue and Qualizza 1999; Barbour et al. 2007; MacKenzie and Naeth 2008, 2010; Brown 2010; MacKenzie 2010, 2011). For all studies cited, the use of upland surface soil within the AOSR was very beneficial for reclamation with respect to native plant establishment and soil quality. Mines located in other regions (e.g., alpine, subtropical and temperate forests, and grasslands) have also shown that salvaging surface soils improves the success of reclaiming diverse, self-sustaining and productive plant communities (Tacey and Glossop 1980; Iverson and Wali 1981; Farmer et al. 1982; Koch et al. 1996; Smyth 1997; Rokich et al. 2000; Holmes 2001; Zhang et al. 2001).

Soil Quality: Upland surface soil is essential to the maintenance of nutrient cycles and maintaining productive forests (Fisher and Binkley 2000). Upland surface soil contains an abundant source of macro- and micronutrients, some of which may be deficient in peat-mineral mixes (e.g., phosphorous and potassium), and it also provides a rich source of organic matter, microbial biomass and soil fauna (McMillan 2005; Battigelli 2006; MacKenzie 2006, 2011; Brown 2010). The forest floor contains the majority of organic matter, macro- and micronutrients within upland surface soil and the Ae horizon contains a nutrient rich source of mineral soil (Strong and La Roi 1985; Fisher and Binkley 2000). The carbon to nitrogen ratio and pH of upland surface soil is generally more comparable to undisturbed upland forests versus peat-mineral mixes created with coarse mineral soil. On older reclaimed sites, differences are less noticeable for upland surface soil and peat-mineral mixes that had fine-textured mineral soil (McMillian 2005; MacKenzie 2006, 2011; Brown 2010).

Propagules: Upland surface soils contain an abundant and diverse source of seed and plant propagules (Whittle et al. 1997; Qi and Scarratt 1998; Rydgren et al. 2004). The majority of propagules within upland surface soils are contained in the organic layer and upper few centimetres of mineral soil (Strong and La Roi 1983; Fyles 1989; Qi and Scarratt 1998; Whittle et al. 1998). Seed and root distribution in soil is affected by particle size. Propagules are found deeper in coarse-textured soils than in fine-textured soils. Large pores in coarse-textured soils allow seed dispersal deeper into the profile (Chambers et al. 1991) and roots penetrate deeper to obtain available nutrients and water (Schenk and Jackson 2002).

Salvage Depth: Successful plant establishment from upland surface soils is largely dependent on salvage depth. Varying the salvage depth has a direct impact on the proportion of organic matter in the reclamation material, which in turn affects soil nutrient status (MacKenzie 2011). Increasing the salvage depth results in a greater proportion of mineral material salvaged. This dilutes the nutrient-rich surface organic horizon with the less nutrient-rich underlying mineral horizon(s). Shallower salvage depths create a soil medium with higher organic carbon content and a higher quantity of plant available macro- and micronutrients compared to deeper salvage depths. However, there may be an increase in the quantity of some plant available nutrients (e.g., phosphorous in Bm horizon) if the soils are salvaged deeper. Shallow salvage depths do not imply only salvaging the forest floor, as incorporating some mineral soil is an important component to creating a new surface soil. The mineral portion (Ae horizon) of the upland surface soil helps create a sustainable surface soil in the event of a forest fire and also provides nutrients and a medium for roots to anchor.

Varying salvage depth impacts propagule abundance and may impact subsequent plant re-establishment in reclamation. The general consensus from research shows that shallower salvage depths compared to deeper salvage depths results in increased recruitment of native plant species from in situ propagules. Rokich et al. (2000) reported greater *Banksiana* species recruitment on a bauxite mine when the surface soil was salvaged at 10 cm (254 seedlings per 5 m^2) compared to 30 cm (81 seedlings per 5 m^2). Tacey and Glossop (1980) found stripping the top 5 cm of topsoil significantly increased plant seedling establishment compared to stripping to 40 cm in the Jarrah forest. The effects of salvage depth are also applicable to non-vascular plant species, Rochefort et al. (2003) determined significantly greater establishment of *Sphagnum capitula* from spreading 0 to10 cm of the surface soil of a peatland compared to spreading deeper layers. Research has shown that the number of plant species or woody plant stems that establish do not differ greatly when the upland surface soil salvage depth is 10 cm, 15 cm or 30 cm; however, the total plant density and percent live cover is greater when upland surface soils are salvaged at shallower depths (MacKenzie 2011). More plants establish if shallow salvage depths (< 10 to 15 cm) are used for species that rely on regeneration from seed banks (e.g., jack pine and black spruce) as opposed to bud banks (MacKenzie 2011).

Figure 1 displays a general trend of viable propagule bank density decreasing with increasing soil depth within two different soil textures found within the AOSR (Mackenzie 2006, 2011). This trend is similar to seed bank densities found in the boreal forest and other forest types (Moore and Wein 1977; Granström 1986; Kramer and Johnson 1987; Hills and Morris 1992). The distribution of roots follows a similar trend as the soil seed bank; however, the density of roots capable of propagation extend deeper within the soil profile compared to seeds (Strong and La Roi 1983).

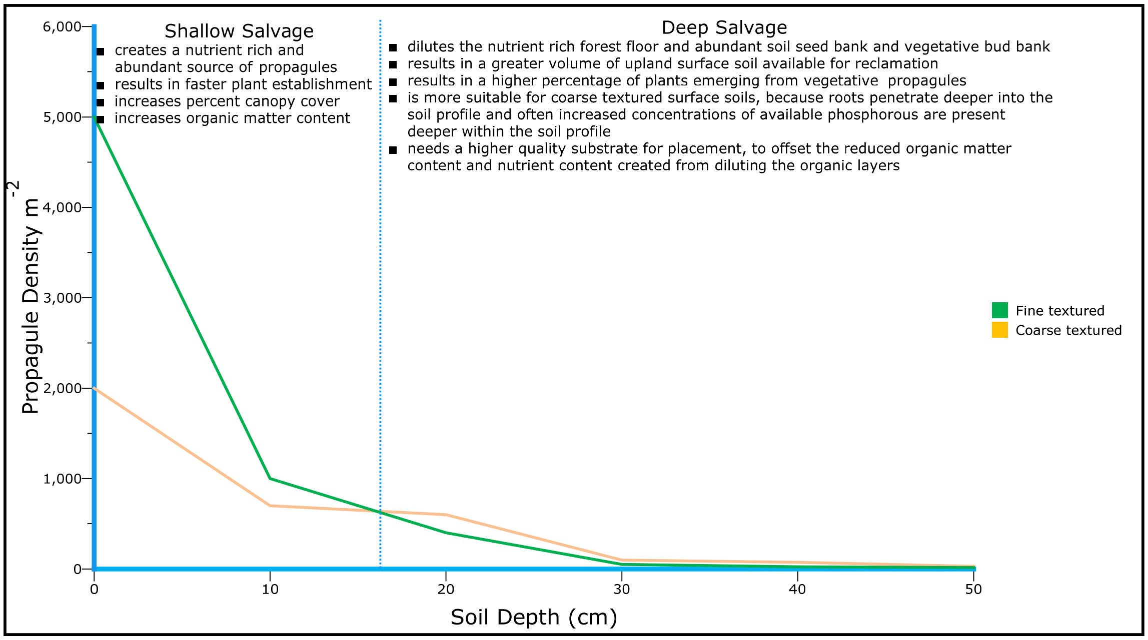

Figure 1. Generalized schematic displaying changes in propagule density with increasing upland surface soil depth for two different soil textures.

Shallow salvage depths often result in higher cover values for most species within most plant groups; however, responses are species-specific. When upland surface soil is applied to better quality substrates, there are fewer differences between shallow and deep salvage depths in the resulting canopy cover. When salvaged upland surface soil is placed on lower quality substrates, upland surface soil salvaged from shallow depths (10 to 15 cm) showed increased canopy covers for most plant groups when compared to upland surface soil salvaged from deeper salvage depths (20 to 30 cm) (MacKenzie 2011).

For additional information on woody plant establishment or densities using upland surface soil, refer to the *Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region* (Alberta Environment 2010).

Ecosite: As a result of different chemical and physical soil properties and moisture regimes, ecosites differ in plant species composition and abundance. For upland surface soil salvage, ecosites are grouped into two broad categories that are characterized by coarse- or fine-textured soil. Coarse-textured soils are typically found in a/b ecosites while other ecosites (c, d, e and g) have finer textured soils. However, coarse-textured soils with an SMR of submesic or wetter can be classified as c, d, e or g ecosites. The depth of the forest floor and Ae horizon generally increases on more nutrient-rich, well-drained ecosites. Similarly, the propagule abundance is often greater within these more productive ecosites and the proportion of the propagule bank contributed from seed and herbaceous plants is also greater (Fyles 1989; Qi and Scarratt 1998; Whittle et al. 1998; Mackenzie and Naeth 2007; MacKenzie 2011).

Image 7. Natural re-growth of trees, shrubs and herbaceous plants after upland surface soil has been salvaged 15 cm deep.
Picture displays the potential for farming LFH and propagules.

Management Implications:

The intent of upland surface soil salvage is to salvage an appropriate mix of LFH and underlying soil material to preserve soil quality and seeds/propagules. Since it is recognized that LFH and A horizons of undisturbed soils in the AOSR vary depending on their soil texture, appropriate salvage depths vary depending on soil texture. Where the soil texture is coarse, the maximum salvage depth of upland surface soil should be 15 cm or to the bottom of the Ae horizon (whichever is greater) from all land to be disturbed. Where the soil texture is fine, the maximum salvage depth should be 30 cm or to the bottom of the Ae horizon, (whichever is less) from all land to be disturbed. The change in colour from a light grey/white Ae horizon to a dark brown/brown Bt/Bm horizon is often a more practical guide for operators to use when salvaging upland surface soils; however, a depth needs to be applied when no Ae horizon exists. The above guidelines are recommended when upland surface soil is stockpiled or when there are no definitive plans for its use.

To meet a life of mine material balance requirement, operators may need to deviate from the prescribed upland surface soil salvage depth(s). Operators must be aware that any deviations may have a corresponding impact to the soil quality and propagules. Deviations are managed through EPEA approvals and require authorization.

There may be occasions when extremely steep slopes prevent salvaging upland surface soil because of safety issues; however, attempts should be made to recover as much of the upland surface soil as possible.

Operators must consider the trade-offs presented in Table 2 when establishing upland surface soil salvage depth.

Table 2. Upland Surface Soil Salvage Depth Trade-Offs

Salvage Depth	Soil Quality	Propagule Abundance	Material Volume
Thin	↑	↑	↓
Thick	↓	↓	↑

<u>Adaptive Management:</u>

Upland surface soil is a limited reclamation material resource due to its limited extent in the pre-disturbance landscape. Adaptive management techniques should consider ways to preserve this resource and maximize its use in the reclaimed landscape. Mixing upland surface soil with other reclamation materials during salvage should be avoided to reduce dilution of viable propagules contained within the upland surface soil and to ensure availability of segregated materials for direct placement opportunities. The most effective way to prevent mixing of reclamation materials during salvage is to segregate different reclamation materials. For example, transitional soil windrows should not be pushed into windrows of upland surface soil or peat-mineral mix. The ability to segregate upland surface soils during salvage operations depends on the scale of the salvage operations and size of transitional soil and upland surface soil polygons.

Operators should salvage upland surface soil using recommended depths for specified uses of the reclamation material when directly placed. Knowledge of the placement area and storage conditions will help determine the most appropriate salvage depth to maximize the value of the soil. The depth of soil salvage impacts the physical, chemical and biological properties of the soil and these changes affect how the upland surface soils should be placed as a reclamation material. In most cases the placement area will have a predetermined end land-use. The type of reclamation material used for subsoil on post-disturbance landscapes should also be predetermined.

Recommending one salvage depth for all soil types is not considered best practice because the use of the salvaged soil may not be optimized. For example, salvaging soil to a greater depth (20 to 30 cm) increases the volume of material available for reclamation; however, the increased depth limits its suitability as a propagule source for revegetation and may reduce the organic matter content. Placing upland surface soil salvaged from shallow depths (10 to 15 cm) on selectively salvaged subsoil with the intent of creating lots of biomass may not utilize the upland surface soil efficiently. Salvaging shallower depths of surface soils (10 to 15 cm) generally increases the proportion of viable propagules in these materials, but reduces the volume recovered for reclamation use. These examples demonstrate that there are different approaches for managing and using salvaged upland surface soil.

The use of pre-disturbance soil survey data and field observations (i.e., texture/colour change) to determine actual depths of upland surface soil may provide better guidance on salvage depth than basing the salvage on general salvage depths.

Propagule Source: Using upland surface soil as a propagule source differs from using it as a soil medium, because the soil propagules and/or microorganisms are the main value and the soil quality is less important. Salvaging upland surface soil for the propagules would be considered best practice when placing them: (1) on post-disturbance landscapes capped with peat-mineral mixes; (2) on upland surface soil that has been previously stockpiled for a long period of time; and (3) when high establishment rates of native boreal species are required. When using upland surface soils as a propagule source, the maximum salvage depth should be no more than 5 cm below the forest floor. Below 5 cm the abundance of seed is low; therefore, increasing salvage depth dilutes the abundant source contained within the forest floor layer and upper 5 cm of mineral soil.

Productivity and Diversity: Different plant communities may require different amounts of soil nutrients and organic matter to maintain site productivity. In addition, there are different expectations with respect to diversity. In general, shallower salvage depths result in materials with higher nutrient concentrations (particularly N) and with higher proportions of viable propagules. Therefore shallower salvage depths should be targeted where reclaimed site productivity and/or species diversity are primary objectives. Deeper salvage depths should be targeted where the primary objective is obtaining maximum reclamation material volumes. Note that deeper salvage might be used to dilute propagule banks (e.g., where a salvage area has abundant competitive plant species such as marsh reed grass [*Calamagrostis canadensis*], deeper salvage might be used to dilute propagules of this species in the reclaimed soil). The amount of soil nutrients, organic matter and abundance of seeds and roots decrease with increasing depths (Fyles 1989; Strong and La Roi 1985); therefore, it is intuitive that shallower salvage depths would provide a surface soil that contains more nutrients, organic matter and propagules than deeper salvage depths. Mackenzie (2011) found shallower salvage depths resulted in more plant species establishing and greater canopy cover of live vegetation compared to deeper salvage depths. Similarly, shallow salvage depths contained more organic matter and macro- and micronutrients then deep salvage depths (MacKenzie 2011). Upland surface soil salvage depths should generally not exceed 30 cm.

Salvage depths can be expressed as a ratio of forest floor (organic) to mineral soil, where shallow salvage might have ratios of 1:1 to 1:2, while deeper salvage might have ratios of 1:3 to 1:5. Where fine-textured upland surface soils are salvaged primarily as propagule sources, it is recommended that shallower salvage depths (e.g., maximum 1:3 forest floor to mineral ratio) be used, as seeds and roots may have difficulty emerging through these soils with higher clay contents (Benvenuti 2003). For coarser-textured soils, deeper salvage depths (e.g., 1:5) can be used. Operational constraints may force operators to deviate from the recommended salvage depths. If soils are salvaged deeper than the recommended salvage depths longer time frames or additional management will likely be required to achieve comparable productivity and/or diversity. The ratios provided are examples only and they were derived from preliminary results from MacKenzie (2011); further research on the long-term sustainability of these ratios will be required to make more definitive ratios.

Placement Area: Some reclamation materials (e.g., suitable overburden) contain fewer nutrients, organic carbon and biological activity than peat-mineral mix or subsoil. Consequently, deeper salvage depths may be used when applying upland surface soil on better quality reclamation materials such as peat-mineral mix or subsoil. Shallower salvage depths should be used if upland surface soils are placed on steep slopes (i.e., >25%). This guideline is not based on empirical evidence; rather, it is a conservative estimate to prevent loss of the replaced soil due to erosion. Surface soil containing more organic matter and WD is less prone to erosion (Harmon et al. 1986; Fisher and Binkley 2000).

Image 8. A slash pile moved to recover the upland surface soil underneath. This is considered a best practice.

Knowledge Gaps:

The majority of handling techniques derived from research using upland surface soil for reclamation in the AOSR are based on results from short-term monitoring programs. Due to the recent application of upland surface soil there are limited data to suggest we know conclusively how to best handle upland surface soil. It is critical that research projects and large scale operational projects are monitored over the long term; this will allow operators to gain a better understanding of how various salvage and placement practices affect the long-term sustainability of the soil quality and plant communities.

The effects of salvage depth and possible interactions with placement depth and substrate quality using upland surface soils developed on fine-textured parent material needs assessment at an operational scale. Although a similar project has been established using small plots (1.5 m x 1.5 m), highly controlled experiments such as this do not accurately represent how materials are handled using large equipment. Results obtained from small plots may not accurately represent the operational outcome.

Salvaging small plugs of the forest floor layer with the upper Ae horizon and placing them adjacent to transplanted trees on areas reclaimed with peat-mineral mix requires assessment. Using plugs from upland soil could provide a source of nutrients and mycorrhizae for the planted trees, in addition to providing an inoculation of seeds, roots and microorganisms on peat-mineral mixes. Mixing the two horizons together or only using the forest floor layer should also be assessed. These factors may impact the overall efficiency of this processes application.

Image 9. Upland surface soil salvaged to a depth of 10 to 15 cm on a b ecosite.

Image 10. Upland surface soil salvaged to a depth of 25 to 30 cm on a b ecosite.

Image 11. Upland surface soil salvage of a d ecosite in winter.

TRANSITIONAL SOIL SALVAGE

BMP 5 Salvage transitional soils.

Rationale

The biological and nutrient capital of transitional soils makes it a valuable reclamation material. The identification of transitional soils is based upon several beneficial properties including but not limited to:

- A high level of biodiversity contained within the soil and plant communities;
- An abundant and diverse representation of soil organisms;
- A diverse representation of vascular and non-vascular propagules;
- Soil macroinvertebrate and meso/micro fauna;
- Good organic matter and mineral mix ratio quality; and
- A rich source of soil nutrients.

Transitional ecosystems have distinct vegetation and soil characteristics resulting from their landscape position and these ecotones provide multiple ecological benefits and help create and preserve healthy aquatic ecosystems. Salvaging transitional soils is one method that can be used to transfer the benefits from pre-mined areas back onto reclaimed landscapes.

Current Practice/Strategy:

Transitional soils have not been commonly salvaged separately and only some of the EPEA approvals require separate salvage of transitional soils. Salvaging transitional soils is typically restricted to winter months during frozen ground conditions. Dozers salvage transitional soils into windrows prior to loading in heavy haulers where they are either directly placed or stockpiled with other reclamation materials. The salvage depth varies depending on the operator. Typically transitional soils are salvaged to achieve a stripping ratio of organic to mineral soil between 50:50 and 70:30.

State of Knowledge:

General: Transitional soils are mineral soils developed under forest in locations with imperfect drainage or wetter conditions, typically including an organic horizon less than 40 cm. Transitional soils generally occur on f, g and h ecosites and are ecotones or transition zones between upland forested areas and peatlands/wetlands. There are limited data available about how transitional soils perform as a reclamation material within the AOSR; however, research conducted outside of the AOSR shows forest-wetland transitions as biologically diverse and nutrient rich (Risser 1995).

Soil Quality: Transitional soils have chemical and physical properties intermediate between upland and organic soils. Ecotones control water and nutrient flows across the terrestrial landscape through the soil surface and soil profile which results in concentration of nitrogen and phosphorous in these areas (Risser 1995). However, nitrogen in transitional soils can be lost to the atmosphere when soils are saturated.

The quality of the salvaged organic matter may be better when compared with deep organic soils developed under bog conditions. This is because of the different quality of litter that is decomposed when compared with dominantly decaying *Sphagnum* moss in bogs. The abundance and richness of ectomycorrhizal fungi increases from bogs to upland forests and there is a significant increase in the transitional zone compared to bogs (Wurzburger et al. 2004).

Propagules: The propagule bank contained within transitional forested areas is diverse. Vascular and non-vascular species of upland and peatland areas are often present (Lamb and Mallik 2003). Once salvaged and placed directly onto post-disturbance landscapes, a diverse propagule bank containing both upland and peatland species is available.

Management Implications:

Determining a material balance for transitional soils is difficult, because current AVI methods used for mapping soil units do not provide detailed resolution to separate transitional soils into discrete soil polygons. The volume estimates of transitional soils will be most accurate from a short-term planning perspective using current soil mapping methods.

It is difficult to salvage transitional soils that are wet under non-frozen soil conditions. Salvaging during frozen conditions is also difficult if the frost layer penetrates deep into the soil profile.

Once transitional soils are pushed into windrows, the windrows can look like upland surface soil windrows or peat-mineral mix windrows. Careful attention is required to ensure transitional soils are hauled to the correct stockpile location.

Adaptive Management:

The recommended salvage depth of transitional soils depends on the handling and intended use as a reclamation material. The depth of the organic layer is the main determinant for selecting an appropriate salvage depth. There are no organic to mineral soil ratios provided because most situations are site-specific. The use of qualified monitors in the field is recommended to achieve desired salvage depths. The following factors should be considered when salvaging transitional soils.

Stockpiling: Transitional soils that are to be stockpiled should be preferentially salvaged using a higher proportion of organic soil. Once stockpiled, the additional organic matter helps offset any potential nutrient/organic matter losses within the stockpile over time (Visser et al. 1984; Kundo and Ghose 1997). Transitional soils should be preferentially stockpiled in upland surface soil stockpiles.

Underlying Mineral Soil: Transitional soils used for reclaiming upland forests should be salvaged with an equal proportion of organic and mineral soil. The exact ratio used will depend on the environmental variables present and the quality of underlying mineral soil. Incorporating additional mineral soil within a coversoil composed of transitional soil can improve the soil tilth, which may allow for better root to soil contact through slightly increased bulk densities. Salvaging transitional soils deeper to include more mineral soil reduces the number of propagules of competitive plants present (e.g., herbaceous species found in fens), which may be desirable to help reduce the amount of competition faced by planted trees and shrubs. Incorporating more mineral soil is also desirable if the mineral soil helps improve the pH of the overall mix.

Salvaging transitional soils to include less underlying mineral soil may be desirable if the underlying mineral soil contains chemical or physical properties that will not allow operators to meet their reclamation objectives. Undesirable chemical and physical properties may include oil sands, high pH, heavy clay texture and high coarse fragment content.

Propagules: If transitional soils are salvaged as a source of propagules and are directly placed, then a mix consisting of more organics should be used. The depth will depend on the targeted species: vascular or non-vascular plants. Transitional soils should be salvaged at shallower depths (e.g., 10 to 20 cm versus 30 cm) if non-vascular plants are targeted because spores of non-vascular plants are more concentrated near the surface (Rochefort et al. 2003) compared to seeds and roots (Strong and La Roi 1985; Putwain and Gillham 1990).

Knowledge Gaps:

Current methods of mapping and identifying transitional soils do not adequately distinguish transitional soils from upland surface soils and organic surface soils; survey methods that can more accurately distinguish these soils may need further research. Appropriate salvage depths that provide more definitive guidance need to be researched. Different salvage techniques such as salvage during frozen versus non-frozen conditions should also be researched.

PEAT-MINERAL MIX

BMP 6 Salvage organic soils.

Rationale

Organic soil is an important reclamation material used widely as a coversoil material in the AOSR and makes up the volumes required for coversoil when volumes of upland surface soil are limited. Adding mineral soil to peat to create a peat-mineral mix improves the tilth and reduces the risk of losing organic matter due to rapid decomposition or in the event of a surface fire. Peat-mineral mixes created either during salvage, stockpile or placement help improve the success of reclaiming post-disturbance upland landscapes and are also an abundant source of organic matter that can be salvaged cost-effectively.

Current Practice/Strategy:

A desirable method to salvage peat-mineral mix is to use large hoes or shovels to salvage the peat and underlying mineral soil to the desired ratio. Operators then place the mixed material into haul trucks. The salvaged peat-mineral mix is used immediately for reclamation or is hauled to stockpiles. In some circumstances peat alone may be salvaged separately. Some examples include:

(1) when operational constraints are present (e.g., salvaging peat that is not frozen);
(2) when the underlying mineral material is not suitable for creating a peat-mineral mix (e.g., high clay content and lean oil sand); or
(3) when the peat is to be used to create wetlands.

In some cases, operators mix the organic soil with mineral soil during placement to create peat-mineral mixes. Peat-mineral mixes that are combined with fine-textured mineral soil are usually preferred; however, within some areas of the mineable oil sands region coarse-textured mineral soil is all that is available. Underlying mineral soil that is high in clay content is not preferred, because the clay does not mix evenly with the peat and the resulting mix is peat mixed with clay balls. The peat to mineral ratio targeted for salvage varies from 50:50 to 70:30. Peat-mineral mix ratios are usually variable given the operational constraints and variability of peat depths and physical properties of the underlying mineral soil.

The methods for salvaging peat-mineral mix vary. Accessibility of a salvage area determines the procedures and equipment used. Weather conditions, the depth of frost and the moisture content of the peat and underlying mineral material determine accessibility. Methods used to improve accessibility include pounding the frost layer deep into the organic layer by dragging haul truck tires behind dozers and, if necessary, placing padding (mineral material) on top of peat or at the base of the salvage pit. Accessibility of a salvage area can be improved through the use of smaller equipment and construction of temporary roads to provide equipment access under thawed conditions.

State of Knowledge:

General: Because organic soils are so dominant in the pre-disturbance landscape, salvage of these soils is necessary to meet the regulatory coversoil requirements. Salvage and placement of peat-mineral mix on reclaimed landscapes in the mineable oil sands area is governed by EPEA approvals. Peat-mineral mixes are preferred over peat alone for upland reclamation because the chemical and physical properties of the mixes function more like upland surface soil due to the added mineral component. Additionally, mixing peat with mineral soil is more effective at preventing erosion (Ziemkiewicz et al. 1980). Peat-mineral mixes are usually classed as mineral soils that have less than 17% total organic carbon (Alberta Environment 2006). The majority of the landscape within the AOSR is comprised of organic soils (Lindsay et al. 1962). The amount of organic soils that exist on a mine lease varies among operators. Because of the widespread availability of organic soils, coversoil comprised of peat or peat-mineral mix has been, and will continue to be, the dominant reclamation material used on post-disturbance landscapes for the majority of mines.

Soil Quality: Extensive research on the biological, chemical and physical properties of peat-mineral mix has taken place in the AOSR by a variety of researchers, industry and consultants (Barbour et al. 2007). Peat-mineral mixes provide a surface soil high in organic matter that also has an excellent water holding capacity. The peat-mineral mix allows sufficient infiltration and water storage to release water more slowly into the underlying mineral soil which minimizes preferential flow through cracks. The water flow dynamics of peat-mineral mixes are important for mitigating salt migration into the upper layers of soil cover while supplying available water to plants. The structure of peat-mineral mixes does not restrict root growth.

The nutritional value of peat-mineral mixes depends on the type of peat and the chemical and physical properties of the mineral component used in the mix. The pH of some peat-mineral mixes can be slightly alkaline, but less than 8.0. Various nutrients (e.g., phosphorous, potassium and some micronutrients) are limited in peat-mineral mixes, therefore macronutrients are added in the form of fertilizer.

Nitrogen mineralization rates are usually lower compared to undisturbed upland forests and total nitrogen usually stabilizes in 6 to 13 years after placement. Conflicting research results in the AOSR suggest that micronutrients may be toxic, deficient or sufficient (Barbour et al. 2007). Boron has been identified as being elevated in peat-mineral mixes and in aspen and white spruce tissues.

Organic soils vary in their physical, chemical and biological characteristics. The depth of organic soils within the AOSR varies from 40 cm to more than 1.0 m (Turchenek and Lindsay 1982). Organic soil layers 2.0 to 3.0 cm deep are common. Organic soils developed in fens differ from organic soils developed in bogs. Fen peat is often more decomposed than bog peat, is mesic to humic, has higher pH and base saturation, and has a much lower carbon to nitrogen ratio than bog peat (Monenco Consultants Ltd. 1983; Verhoeven et al. 1990). In addition, fens often have a more abundant soil seed bank than bogs (Moore and Wein 1977; Leck et al. 1989; Jauhiainen 1998).

The depth of peat and water table within the organic soil profile affects the soil characteristics. The chemical and physical quality of organic matter is better near the surface within the organic soil profile (Turetsky 2004). Concentrations of macro- and micronutrients are variable with depth and groundwater flow, because the depth and fluctuations of the water table drive the distribution of nutrients (Damman 1978). In addition, microbial populations are greater close to the surface than they are deep within the soil profile (Waksman and Purvis 1932; Martin et al. 1982; Fisk et al. 2003).

Propagules: The majority of plant seeds, roots and moss spores are contained within the upper 5 to 30 cm of the organic soil profile (Putwain and Gillham 1990; Rochefort et al. 2003; Véerin and Muller 2003). Salvaging the upper 10 cm of the organic layer, which contains the majority of propagules and diaspores, is a common practice used for restoring boreal peatlands in North America (Rochefort et al. 2003; Rochefort and Lode 2006).

Management Implications:

Trafficability on organic soils is an operational constraint that affects salvage practices and has a direct impact on the cost of salvage and the quality of the peat-mineral mix. Organic soils that have not been drained often need more site preparation to ensure that the frost is pounded deep to support heavy equipment traffic. If there is not enough water in the organic soils to promote frost penetration then padding material (that can support heavy equipment) must be imported. When used on top of the organic layer, padding material may get incorporated into the peat-mineral mix, which could reduce the overall quality of the reclamation material. Conditions that prevent equipment from salvaging peat and mineral soils in one lift can create a less desirable peat-mineral mix. Additionally, large frozen blocks of peat do not mix with mineral soil.

Adaptive Management:

Peat:Mineral Ratio: Peat-mineral mixes with a 60:40 peat to soil volume ratio have been used for many years in the AOSR to create an effective coversoil in upland reclamation. The actual or targeted peat-mineral ratio depends on operational constraints and reclamation objectives. Unmixed peat used as an upland surface soil is considered poor quality when compared to peat mixed with mineral soil. Mixing peat with mineral soil to the desired peat-mineral ratio at the pit face during salvage operations is considered the best way to achieve a good peat-mineral mix. However, factors such as the suitability of the underlying mineral soil and the peat depth will determine the effectiveness of this method. If peat is salvaged separately from the underlying mineral soil, efforts should be made to find suitable mineral soil to create a peat-mineral mix.

Soil Quality: There are obvious chemical and physical differences between coarse and fine-textured mineral soils. Placing a coversoil that stores water for plants and flushes salts into lower soil profiles on saline sodic dumps is critical in maintaining a self-sustaining plant community in the AOSR. Peat-mineral mixes can be deficient in macronutrients (e.g., phosphorous and potassium) in the AOSR; therefore, it is important to create a medium that is capable of supplying and storing nutrients to establish and maintain plant growth.

The decision to salvage peat-mineral mixes composed of fine-textured mineral soil versus coarse-textured mineral soil depends on various factors including:

(1) reclamation objectives;
(2) the net benefit of selective salvage; and
(3) the difference between the soil textures of the underlying mineral soil.

Selectively salvaging peat-mineral mixes composed of fine-textured mineral soil in preference to coarse-textured may be beneficial for reclaiming productive mixedwood forests; however, the peat-mineral mix may discourage establishment of dry/poor site types.

When salvaging peat with fine-textured mineral soil to create a peat-mineral mix for an upland coversoil, a homogeneous peat-mineral mix is required. Excluding mineral soil that has a high clay content can help prevent the creation of a poor mix in which the peat is clumped with clay balls resulting in a poorer quality soil amendment.

Propagules: When reclaiming wetlands, operators should salvage the upper layer of organic soils separately if the material is to be directly placed and used to establish native, locally common wetland plant species. The majority of propagules is contained in the top few centimetres of the organic soil profile; therefore, increased salvage depth results in increased dilution of the propagule bank. Within organic soils, rooting depth is confined by the water table and roots are usually present within the upper 30 cm of the soil profile. Seeds and diaspores are contained in the upper 10 cm of the organic soil profile. The upper 40 cm of the organic soil profile is considered the maximum salvage depth. Using shallower salvage depths (e.g., 10 cm) results in a greater density of propagules near the surface when placed. Alternative salvage methods and additional site preparation may be required to salvage organic soils within the upper 40 cm of the profile when compared to salvaging a peat-mineral mix and/or upland surface soils.

Knowledge Gaps:

Additional work is needed to determine if peat-mineral mixes salvaged from fens results in better soil quality and plant establishment compared to bogs. Typically peat from fens has higher quality organic matter and more nutrients compared to peat from bogs; however, it is not clear how different the two sources of peat would be after the materials have been salvaged, stockpiled and placed onto a post-disturbance landscape. More research is needed to determine how different types of peat mixed with mineral soil affect plant establishment, plant growth and nutrient cycling before prioritizing the salvaging of these materials.

Operations have evolved the practice of mixing peat and fine-textured mineral soil during salvage, stockpile and placement; however, there is a lack of empirical data that can be used to suggest an optimal handling method. Further research is required to determine if certain methods (e.g., mixing post-placement via disc versus at salvage) result in a better coversoil when creating peat-mineral mixes. The type of mineral soil that is mixed within the peat should also be assessed to determine the effects on plant community development and soil quality. Given the new techniques used to control erosion, research might be warranted to determine if peat salvaged and placed separately as a coversoil can be as good as peat-mineral mixes. Determining if these techniques can be done at an operations scale would also require evaluation.

PEAT-MINERAL MIX

BMP 7 Avoid incorporating peat with unsuitable underlying mineral soil.

Rationale

Incorporating unsuitable mineral soil with peat to create a peat-mineral mix reduces the quality of the peat and also creates conditions unfavourable for plant growth.

Current Practice/Strategy:

Approval requirements preclude operators from using unsuitable material for reclamation. Unsuitable subsurface materials to be excluded in peat-mineral mixes are defined in Table 9 of the SQC (Alberta Soils Advisory Committee 1987). Operators selectively salvage suitable materials for reclamation and attempt to exclude materials deemed unsuitable based on Table 9 as well as additional parameters not included in Table 9 such as hydrocarbons, carbonates and impermeable layers.

State of Knowledge:

Physical Properties: The SQC identifies unsuitable subsurface material as having coarse fragments (% volume) >70% in mineral soils with a modal texture finer than sandy loam or when coarse fragments are >50% in mineral soils with a modal soil texture of sandy loam or coarser. Coarse fragments are defined as rock or mineral particles greater than 2.0 mm in diameter. Coarse fragments have no available water holding capacity, anion exchange capacity or cation exchange capacity (CEC). When mixed in moderate to high percentages, coarse fragments create a soil with limited ability to retain nutrients or water. A high percentage of coarse fragments in soil increases the soil's overall bulk density and reduces the volume available for roots. A soil of finer texture is more able to hold nutrients and water compared to a coarser textured soil.

Soil texture is used to evaluate suitability and poor textures are found at the end of each spectrum of the soil textural triangle (see Figure 2). Heavy clay, sand and silt alone are rated poorer compared to loams and clay loams. Heavy clays do not mix well with peat and the mix becomes more of a heterogeneous arrangement of peat and lumps of clay. Sand has a lower water holding capacity and lower cation exchange capacity versus finer-textured mineral soil. Although certain soil textures, such as sand and heavy clay are rated as poor suitability for reclamation, texture alone should not be used as a main determining factor when selecting mineral soil for creating peat-mineral mixes. The majority of mine leases are constrained by the type of mineral soil present, and some operators may not have a choice but to select mineral soil that is rated as fair or poor based on soil texture.

Saturation percentage is another physical property used in the evaluation of soil quality. Saturation percentages <15% and >100% are considered unsuitable. At saturation, all soil pore space is occupied by water and no free water collects on the soil surface. The saturation percentage is highly correlated with percent clay and percent organic matter within a soil. Soils with a higher saturation percentage can store more water (e.g., clay and peat) than soils with low saturation percentages (e.g., coarse sand and coarse fragments).

Soil Chemistry: The SQC uses several chemical properties to evaluate the suitability for use in reclamation, which include: pH, electrical conductivity (EC), sodium adsorption ratio (SAR) and $CaCO_3$ equivalent. Unsuitable mineral soils have pH <3.5 or >9.0, EC >8 dS/m, SAR >12 and $CaCO_3$ equivalent >70%. However, a soil with an SAR <20 can be classified as suitable if the mineral soil has a soil texture of sandy loam or coarser and the saturation percentage is <100%. Soil pH at either extreme causes negative effects on plant growth and nutrient availability.

The majority of plants in the boreal forest are not tolerant to high levels of salinity within the root zone (Purdy et al. 2005) and an EC >8 dS/m would interfere with plant growth for most boreal plants. The Revegetation Manual considers an EC in surface soils of 4 dS/m to be the cut off value for forested ecosytems and 2 dS/m for commercial forests. Mineral soils that have SAR values >6 usually have excess amounts of sodium. Excess sodium in soils disperses the soil colloids and clay particles causing reduced water infiltration, poor seed germination from surface crust formation, increased erosion and nutritional disorders for most plants (Havlin et al. 1999). Research is being conducted to determine the effects pH has on various plant species within the AOSR. Mineral soil with a high $CaCO_3$ equivalent is associated with high soil pH. The high pH and excess calcium causes negative effects to plant growth and nutrient availability. Soils containing marl have high $CaCO_3$ equivalent values.

Hydrocarbons: Tar balls or weathered lean oil sands may be naturally present underneath peat. The SQC does not include hydrocarbons in its evaluation on suitability for use in reclamation. Further discussion about the effects of bituminous hydrocarbons on plant growth can be found in Appendix A: Salvage of Reclamation Material with Indigenous Hydrocarbons.

Management Implications:

Identifying and excluding all unsuitable mineral soil underneath organic soils is difficult because of the natural variability of soils in the AOSR. Salvage of in situ mineral materials with peat is the most economical option in creating a peat-mineral mix. This technique has been adopted by the oil sands industry since the inception of oil sands reclamation. Pre-disturbance soil surveys provide operators an opportunity to assess the underlying mineral substrates to determine their potential for use in peat-mineral mixes.

Adaptive Management:

Physical properties should not be used as the main guidance for determining the suitability of mineral soil to be mixed with peat to create a suitable coversoil for reclamation. Chemical parameters such as pH, EC and SAR should be used as the main guidance. It is likely easier to alter the peat-mineral mix ratio to offset any physical soil quality issues created from the mineral soil texture or coarse fragment content than it is to change the pH, EC or SAR. There are natural soils that contain high amounts of coarse fragments, sand and heavy clay. Operators should consider pre-disturbance conditions before excluding various types of mineral soil based on these physical parameters.

Pre-disturbance soil chemical data can be used to characterize the mineral soil to the bottom of the desired salvage depth. This enables operators to avoid mixing the “less suitable” mineral soils with the peat.

Knowledge Gaps:

The knowledge gaps about parameters used to determine the suitability of materials for reclamation are similar to those described in BMP #1.

SUBSOIL AND OVERBURDEN SALVAGE

BMP 8 Salvage subsoil and suitable overburden.

Rationale

Subsoil and suitable overburden are valuable reclamation materials. Once placed on a post-disturbance landscape, they provide plants with:

- A rooting zone that stores nutrients and water;
- A medium for anchorage; and
- A barrier between roots and the potentially harmful elements or compounds that may be present in the underlying substrates such as overburden or tailings sands.

Subsoil and suitable overburden play a major role in closure reclamation soil cover designs. The quality of subsoil and suitable overburden salvaged influences the time frame and management effort required to create self-sustaining boreal forest plant communities. Salvage of subsoil and suitable overburden to meet regulatory requirements is intended to achieve reclamation objectives.

The soil regulatory requirements, spatial scale and soil quality variability of the materials in the undisturbed landscape influence the soil salvage techniques. With adequate pre-disturbance information to characterize subsoil and overburden quality, assuming the quality is suitable, subsoil and suitable overburden can be combined during salvage. In the absence of information to characterize overburden quality, discrete salvage of subsoil materials or reduced salvage depths may be required to minimize admixing of unsuitable overburden with subsoil for reclamation.

Current Practice/Strategy:

Operators are currently required to salvage upland subsoil from disturbance areas. In cases where operators have insufficient volumes of upland subsoil to meet soil reclamation objectives, they may salvage subsoil from locations other than upland and suitable overburden to meet material balance requirements.

Soil-cover design requirements for mine operators require a significant volume of material to be placed over the various substrates constructed in the oil sands (e.g., overburden and tailings structures). To meet the reclamation material balance requirements of these soil-cover designs, mine operators must include suitable overburden in their soil salvage program. There are several reasons why upland subsoil salvage alone will not meet closure reclamation requirements:

- Uplands only comprise a portion of the landscape; the majority of the landscape within the AOSR is comprised of organic soils (Lindsay et al. 1962).
- Upland subsoil (B horizons) in the boreal forest region does not extend to depths of more than 1 m.
- Soil conservation requirements in previous approval periods required less reclamation material to be salvaged than the current requirements. This has resulted in material being lost in previous development periods, and thus, soil volume deficits when applying current regulatory requirements.

To meet reclamation material requirements, operators have adopted various soil salvage techniques. The rationale for several soil salvage techniques is due to the variability of the undisturbed soils in the region, the age of the mine operation, site-specific soils information available for operators to evaluate quality and the lack of direct research to confirm the most appropriate salvage strategy(ies).

Subsoil is generally considered to be suitable for use in reclamation, since it is located within the solum of the undisturbed soils being salvaged. In this case, the risk of incorporating this material in the root zone of reclaimed soils is minimal, because the impact to receptors (e.g., vegetation) can be observed, interpreted and measured in the undisturbed landscape.

To evaluate subsoil and overburden quality for use in reclamation, the soil parameters outlined in Table 9 of the SQC (Alberta Soils Advisory Committee 1987) are applied. In addition, petroleum hydrocarbon concentration is also considered in the evaluation of subsoil and overburden. Exclusion of some of the SQC parameters may be authorized due to site conditions. For example, texture may be excluded for operators located in areas with minimal variability (leases located primarily in Poor rated clay or sand areas).

With respect to SQC parameters, preference is given to those materials with ratings of Good and Fair. If insufficient soil volumes of Good and Fair materials are present, operators are permitted to salvage Poor quality material to make-up the remaining balance. However, in these instances admixing of Poor material with Good and Fair material is not recommended. Assessment of soil material with respect to PHCs varies depending on the operator, location, distribution and/or extent. Refer to Appendix A for more information on salvaging reclamation materials containing indigenous hydrocarbons.

Subsoil and suitable overburden are salvaged during the winter months primarily due to increased accessibility. Equipment used includes small shovels, hoes, dozers and trucks. Recent attempts to salvage subsoil with scrapers have been successful. Large dozers (D8 to D11) may be used to salvage suitable materials from relatively shallow layers (<1.0 m). Subsoil salvage depths typically vary from 0.25 to 1.0 m depending on the subsoil depth and individual operator practice(s). Maximum salvage depths for suitable overburden vary depending on the lease location in the AOSR. Generally the maximum salvage depth is 2.0 to 3.0 m, but occasionally can be as deep as 5.0 m.

State of Knowledge:

Subsoil: Subsoil is defined as the B horizon within the soil profile or solum (Soil Classification Working Group 1998). Soils in the AOSR have undergone pedogenic processes since the last glaciation (approximately 10,000 years ago). As a result of these pedogenic processes, the subsoil has undergone greater weathering in relation to underlying parent geologic materials. In this case, the subsoil has undergone changes and/or improvements that may make the material more conducive to receptors such as vegetation and soil organisms. These improvements can be either in chemical or physical properties. Subsoil may have greater plant-available nutrients and soil biota than underlying parent geologic materials (Strong and La Roi 1985; Huang and Schoenau 1996; Arocena and Sanborn 1999; Jobbágy and Jackson 2001) and improved structure that has developed from freeze-thaw cycles, wet-dry cycles, soil fauna, microorganisms and roots (Fisher and Binkley 2000). The benefit of using subsoil in relation to underlying parent geologic materials is that its influence on environmental receptors (e.g., plants) can be directly observed and measured in the native soils from which they originate. Therefore, we can make better predictions on the impact that subsoil will have on reclamation performance.

Subsoil can be classified as several forms of B horizons based on their characteristics and stage of development. Soil B horizons present in the AOSR are generally classified into two broad categories: Bt and Bm, which are indicative of their parent geologic material. For soils developed on finer-textured parent materials, a Bt horizon is present, which is characterized by an accumulation of clays leached from the eluvial horizon above (Ae horizon). It is generally darker in colour than the Ae horizon and has well defined blocky to sub-angular blocky structure (Soil Classification Working Group 1998). Soils developed on coarser textured parent geologic materials generally are characterized with a Bm horizon. Oxidation within this horizon results in a reddish-brown colour. Due to the coarse soil texture, Bm horizons typically have no structure and are classified as single-grained.

B horizon variants of significance are also present in the AOSR. Gleyed phases and variants occur on wetter sites. Soils with periodic or prolonged saturation are classified with g or gj suffixes depending on the degree of wetness. Additional inclusions in the landscape that can indicate soil quality include the presence of carbonate (k) and elevated sodium concentration in relation to calcium (n). Gleyed soils (g and gj) are not relevant to characterization of soil quality, but carbonates and elevated sodium subsoils can have a negative impact to soil quality that may need to be considered in soil salvage.

Suitable Overburden: Suitable overburden consists of all material underlying the subsoil to the depth of unsuitable overburden. It also includes the mineral material below the peat layer of an Organic soil. Near the soil surface (directly below the subsoil or peat layer) the C horizon may have undergone secondary accumulation of carbonates (k/ca) and/or soluble salts (s/sa; Soil Classification Working Group 1998). These horizons may also be classified as gleyed phases and variants based on the degree of wetness. Below the C horizon is parent geologic material that has undergone negligible soil development. Since the C horizon directly underlying subsoil has undergone minimal soil development, it is generally not considered to be as high quality as the subsoil.

Suitable overburden salvaged for use in reclamation in the AOSR is primarily the same parent geologic material on which the soils of the area have developed (same as the overlying coversoil and subsoil salvaged for reclamation). These are Quaternary Period deposits (primarily Pleistocene with a minor proportion of Holocene). Pleistocene and Holocene deposits are further classified into their depositional environment. These are predominantly fluvial, glacial and lacustrine. Fluvial materials are generally coarse-textured, glacial materials are medium to fine-textured and lacustrine materials are fine to very fine-textured. Physical and chemical properties (e.g., texture, pH, SAR, EC and PHC) can vary among (and within) each parent geologic material type.

Underlying Pleistocene and Holocene geologic formations are Cretaceous Period deposits. The formations making up Cretaceous deposits are generally considered to be unsuitable for use as reclamation material for several reasons. Cretaceous Period, Clearwater Formation materials are marine shales with elevated salinity and sodicity, and high clay content that makes them prone to shrinking/swelling. In some regions within the AOSR the Cretaceous deposits may have elevated PHCs and are classified as lean oil sand.

Appropriate Salvage: Previous research in the oil sands and mine operations throughout the world has demonstrated the importance of salvaging subsoil and/or suitable overburden to develop a two-lift reclamation soil cover design (Doll 1984; Barbour et al. 2007). In a two-lift soil cover design, subsoil and/or suitable overburden is generally used to create a reclaimed soil profile containing a secondary mineral horizon overlain by a coversoil horizon. A two-lift approach has been adopted as a best practice for mine reclamation in some parts of the United States (Norman et al. 1997), the United Kingdom (McRae 1989) and

Australia (Koch 1997). The secondary mineral horizon provides a buffer for vegetation (rooting) from the substrates of poorer quality. In the absence of this secondary horizon, coversoil alone may not provide an adequate depth for rooting and a suitable buffer from substrates with marginal soil properties (Power et al. 1981; Barbour et al. 2007).

Some of the soil impediments identified in the oil sands include chemical properties such as EC, high pH, SAR and petroleum hydrocarbon content, and physical properties such as high stone or clay content. In the mineable oil sands region, the subsoil and underlying suitable overburden originate within the same geologic deposit; however, the soil development processes which have taken place in the subsoil may have altered the soil quality relative to the underlying parent geologic material. Elements found in the subsoil are likely present in the underlying materials, but the concentrations of the underlying deposit may vary from too low to toxic (Fisher and Binkley 2000). Overburden can be deficient in nitrogen, phosphorous, sulphur and potassium, or nutrients may be present in unavailable forms (Hargis and Redente 1984; Strong and La Roi 1985; Halvorson 1989; Fisher and Binkley 2000). Specific to the oil sands region, Lanoue (2003) found elevated concentrations of available phosphorus in coarse-textured undisturbed soils, especially in the B horizon. Conversely, some properties of suitable overburden may be similar to or better than subsoil for supporting plant growth (Chichester and Hauser 1984). Therefore, the variability in soil quality between subsoil and overburden, as well as the variability within each, must be considered when developing soil salvage plans.

Although the importance of subsoil and suitable overburden salvage has been demonstrated, establishing appropriate salvage technique(s) for the oil sands mining industry is not well understood. Research at an Illinois mine showed increased agriculture crop yields when topsoil was placed over salvaged soil from the upper 1.0 m compared to topsoil placed over materials salvaged from 3.0, 4.5 and 6.0 m depths (McSweeney et al. 1987). Conversely, McSweeney (1981) also found similar to better yields and growth of soybean when topsoil was placed over subsoil with deeper overburden compared to topsoil placed over selectively salvaged B horizon material.

Reclamation research outside the oil sands region must be viewed with caution as the results may not be representative of oil sands mine activities. Variable soil reclamation materials, substrates, landscapes, climate, stakeholder objectives and regulatory requirements can limit the applicability of research from outside the oil sands mine region. It is also important to note that reclamation research conducted within the oil sands may also not be representative across the entire region. Soils across the oil sands region and the closure landscapes that are to be reclaimed can vary, which results in different soil reclamation materials and cover designs being available. Therefore, research results from studies in the oil sands may not applicable across the range of soil reclamation conditions.

Empirical evidence for oil sands reclamation performance is also limited. Oil sands mine reclamation is a relatively new industry, and thus, it is difficult to interpret the performance of currently reclaimed areas that are still relatively young. Current reclamation performance (good or bad) may not be indicative of future performance or sustainability. Evolution of reclamation techniques further limits the ability to measure reclamation performance; current reclamation techniques may not have been adopted in earlier years, which minimize the area available for comparative measurement.

Management Implications:

Evaluation of subsoil and overburden (i.e., suitable overburden and unsuitable overburden) to determine maximum salvage depths requires the commitment from operators to plan year(s) in advance of mine activities. In some circumstances this may not be an option available to operators.

Soil parameters to consider in quality characterization may vary depending on site-specific soil conditions and reclamation objectives. Soil constraints can vary depending on parent geologic material or landscape location. Operators should be aware of these changes and adjust their sampling or field characterization practices if the quality of the material salvaged can be enhanced.

Operators must consider long-term reclamation material balance requirements in their subsoil/suitable overburden salvage strategies. Shallower salvage may result in better quality material for reclamation in the early stages, but may result in a shortfall in later years of reclamation. On the other hand, over-salvage can result in additional operating costs and an increased disturbance footprint for storage. Maintaining an accurate long-term reclamation material balance will optimize the soil salvage activities during the life of the mine.

The logistical constraints of segregating subsoil or a shallow lift (e.g., 1 m) may limit the opportunity to salvage this material. Excessive traffic during winter months can push the frost layer deep within the subsoil layer, which limits the opportunity to salvage thin lifts. In addition, the frozen material salvaged may be difficult to re-spread during direct placement. Conversely, excessive wetness during non-frozen conditions limits equipment accessibility for soil salvage. Additional planning (e.g., equipment selection and timing) and site preparation (e.g., site padding) need to be considered in advance of salvage operations for effective thin-lift salvage.

Adaptive Management:

Even though unknowns remain with appropriate salvage techniques for subsoil and suitable overburden in the mineable oil sands region, there are management practices that operators can adopt at this time to increase the chance of success in reclamation.

Pre-disturbance soil and overburden data to evaluate soil quality for salvage can be a valuable aid to identify the depth and extent of subsoil and suitable overburden. Based on this information, appropriate salvage depth(s) of subsoil and suitable overburden can be established, and thus, minimize the risk of incorporating marginal material with targeted soil reclamation material. If overburden physical and chemical characteristics are known in advance of mining, it is possible to identify material with favourable physical and chemical properties and avoid potential soil constraints (McFee et al. 1981). Even though this strategy is a greater cost to operators during the planning stage, there are advantages to this approach. Pre-disturbance soil and overburden quality data provides greater clarity and confidence to operators when determining maximum salvage depths. It also maximizes the amount of suitable material that can be salvaged, and conversely minimizes the amount of suitable material that is lost in the mine process (removed and mixed with unsuitable overburden). This approach may also result in time and cost savings during salvage. Determining maximum salvage depths prior to salvage operations can result in less confusion during the most active period of soil salvage. A further benefit to this approach is that the environmental monitors supervising the salvage operations may not need to be highly qualified in the soil science discipline. This approach requires qualified soil science personnel to be involved in the planning phase and the environmental monitor’s role is to ensure the field crews steward to the soil salvage plan and identify any additional observations/concerns that may not have been identified in the pre-disturbance characterization process.

In the absence of pre-disturbance soil and overburden data to characterize and distinguish subsoil, suitable overburden and unsuitable overburden, operators may have to adopt a more conservative soil salvage approach. Operators may consider a reasonable salvage depth that will minimize the potential of marginal overburden at greater depths being salvaged with better materials near the surface. Establishment of a suitable depth should be based on the depth of soil development that has taken place in the oil sands region and the surficial geologic material characteristics of the local area. In these instances, oil sand operators may select depths that are intended to salvage primarily the subsoil horizon (e.g., 0.5 m) or the subsoil plus a portion of the underlying horizon (e.g., 1 m). The benefit of this technique is that it provides operators an opportunity to advance their soil salvage program when minimal pre-disturbance soils information is available (e.g., during initial stage of mine development). It also strikes a balance between salvaging a sufficient volume of material to meet the reclamation materials balance requirements, while minimizing the risk of degrading the quality of the reclamation material via incorporation of marginal substrates from greater depths.

Operators should be aware of the potential disadvantages of these approaches. Use of pre-disturbance soil data to determine maximum salvage depths can result in depths commonly extending to 2.0 to 3.0 m, which is well below the root zone for most boreal forest vegetation (Strong and La Roi 1983; Macyk and Richens 2007). Therefore, use of this technique puts greater importance on the parameters that are evaluated and their threshold values. If critical parameters are not included in the evaluation of soil quality, or the values/ranges of the parameters considered are not reflective of the actual thresholds for environmental receptors, there is a risk that poorer quality material may be salvaged for reclamation. Decreasing the salvage depth to just subsoil, or subsoil and a portion of the underlying horizon, also has its disadvantages. Since these volumes may only make-up a portion of the required material balance, additional materials must be salvaged to cover the volume deficit. If the additional material to make up the balance is salvaged indiscriminately there is potential that poor quality material may ultimately be used in reclamation. In the case of salvaging subsoil and a portion of underlying material (e.g., 1 m) there is also the potential to degrade the quality of the subsoil by admixing poorer quality material from the underlying horizon (C horizon). Subsoil (B horizons) has undergone weathering which has resulted in potential translocation of carbonates and/or soluble salts to the underlying C horizon. This can result in the C horizon soil quality being as poor as (or poorer than) the underlying parent material. Admixing of the C and B horizons could negate the benefits and undo the positive soil development processes that have taken place in the B horizon.

Knowledge Gaps:

Although the knowledge and experience gained to date have been used to identify the ‘general’ soil parameters of interest, there are still uncertainties as to which soil parameters require the greatest awareness and if these key parameters are consistent across the region (or key parameters vary across the region with different soil types). Furthermore, the threshold values or ranges of the soil quality parameters currently in use may not be accurate or representative of environmental conditions. In some cases these guidelines are dated and/or do not reflect the soil conditions of the area, or the values do not reflect the current stakeholder objectives. For example, since the publication of the SQC guidelines (Alberta Soil Advisory Committee 1987), stakeholder requirements for oil sands operators have evolved from a goal that emphasized forest land productivity to one now that reflects forest community re-establishment. To address stakeholder concerns, research has been conducted, and thus, the SQC may not reflect these advances in our understanding of soil reclamation to meet these new oil sands reclamation goals. The effects of pH on various native boreal plants are currently being assessed, which may further our understanding of the effect of soil pH on vegetation in the AOSR.

Soil parameters currently used to characterize quality may not cover the entire range of the key soil parameters for characterization. Additional research is required to determine toxic, sufficient and deficient levels of macro- and micro-nutrient concentrations and chemical substances in boreal forest soils. At this time, identification of specific nutrients, and determination if their importance is widespread across the region (or site specific), needs to be investigated.

There is growing interest in discrete salvage of subsoil and suitable overburden. The net benefit of separate salvage of these materials within the AOSR requires research. Although there are perceived benefits to discrete salvage of subsoil and suitable overburden, there are several issues and constraints that can negate the benefit of this approach. The performance of a soil is not only influenced by the materials used in soil reclamation (e.g., subsoil, suitable overburden), but is also influenced by the landform (or substrate) that is reclaimed. If the substrate has a greater influence on soil reclamation performance than the subsoil/overburden material quality, there may no advantage of separate salvage of subsoil/suitable overburden. If key soil parameters can be established, separate salvage of subsoil/suitable overburden may improve reclamation performance. However, as mentioned previously, further research is required to identify these key soil parameters need.

The appropriate use (placement) of separately salvaged subsoil and suitable overburden materials also has not been explored. Since this technique requires greater effort and operation costs, these materials should be used appropriately in reclamation. The appropriate placement techniques on various landforms and depths within these landscapes have not been confirmed.

Separation of suitable overburden materials (upland and lowland) may also require further research work. Lowland suitable overburden salvage comprises a large proportion of the mineral material salvage. Due to the different landscape locations of upland and lowland suitable overburden, there may be differences in soil quality that are not being considered in soil quality characterization. Further research may be required to determine if upland suitable overburden has more desirable chemical characteristics compared to lowland suitable overburden.

SEGREGATION OF RECLAMATION MATERIAL

BMP 9 Segregate coarse-textured upland soils from fine-textured upland soils.

Rationale

Soil texture and structure significantly affect the water and nutrient dynamics of a soil. The texture of a soil will not change during salvage, storage or placement activities unless soils with different textures are mixed together (as soil particle-size distributions are produced through physical and chemical weathering processes that are operative over far longer time frames than those occurring in the oil sands mining disturbance – reclamation cycle; Brady and Weil 2002). A synthesis of oil sands mine reclamation research has shown that soil structure is not adversely affected by winter soil-handling operations, and that “reclaimed soils exhibit soil physical properties not significantly different from similar textured soils in undisturbed areas” (Barbour et al. 2007). This same synthesis identifies use of different soil textures as a key mechanism in determining post-reclamation ecological characteristics: “Ecosites developed on coarse-textured soils (a/b ecosites) have poorer nutrient regimes and drier moisture regimes than those of ecosites developed on fine-textured soils (d ecosites). Soil capping practices suitable for achieving these various ecosites should be designed accordingly.” Because of the influence of soil texture and structure on moisture retention, and because these properties can be maintained through the soil handling cycle, segregating coarse-textured soil from fine-textured soil for both upland surface soil and B-horizon subsoil will help preserve each soil’s capability for reclaiming different site types and diverse ecosystems.

The spatial scale and variability of how soils with different textures are naturally segregated needs to be considered prior to segregating different soil textures.

Current Practice/Strategy:

EPEA approvals require operators to segregate coarse-textured soil from fine-textured soil. The most recent EPEA approval requires operators to minimize the mixing of the two types of salvaged upland surface soils (a/b ecosites and all other upland ecosites) which reflects the different textures of these materials. The approval also requires operators to minimize the mixing of coarse- and fine-textured subsoils. The soil salvage and placement plan identifies soil polygons of different soil textures using AVI maps and soil textures are verified during pre-disturbance soil-sampling programs and/or during salvage operations.

State of Knowledge:

Soil texture is an important consideration as it impacts forest growth through indirect effects on soil water-holding capacity, aeration and organic matter/nutrient retention (Fisher and Binkley 2000). The size distribution of the mineral particles determines the texture of a given soil. Mineral soil particles are usually grouped into three broad textural classes: sands, silts and clays. The combinations of these classes are used to indicate textures (Figure 2). For the purpose of AOSR mine reclamation, texture is grouped into two broad categories: fine and coarse. Fine-textured soils are typically more nutrient rich, have a greater cation exchange capacity and contain greater amounts of organic matter compared to coarse-textured soils (Bauhus et al. 1998; Fisher and Binkley 2000). The increased surface area and charge of fine-textured mineral soil has significant effects on water potential and retention, organic matter binding, cation exchange and overall biotic activity.

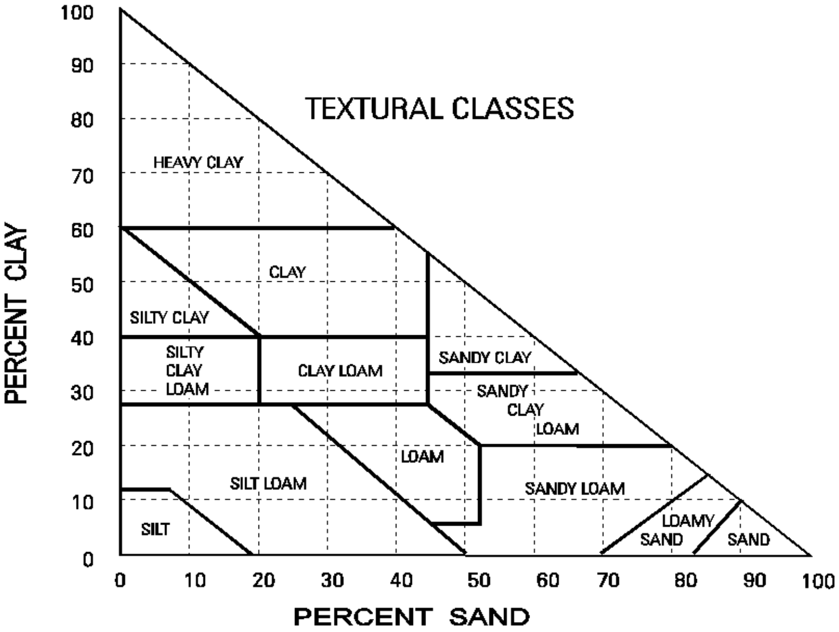

Figure 2. Soil textural triangle (Agriculture Canada 1976).

Different soil textures usually support different types of plant communities because of different moisture- and nutrient-retention properties. Edaphic factors such as soil texture can have a profound effect on species composition and diversity (Host and Pregitzer 1992; van Breemen et al. 1997). For example, deep coarse sandy soils typically support pure stands of jack pine (Monenco Consultants Ltd. 1980). Some sands have lenses of finer-textured materials – even finer-textured sands – and variations in texture such as these lenses strongly influence soil water retention which in turn can strongly influence species composition. Barbour et al.'s soil capping research synthesis document indicates that use of fine-textured materials is a key mechanism for re-establishment of mesic ecosites on reclaimed oil sands mining areas, while use of coarse-textured materials is recommended for sub-mesic and drier ecosites (Barbour et al. 2007). Therefore, homogenizing coarse- and fine-textured materials during soil handling limits options for establishing different types of plant communities on post-disturbance landscapes.

Management Implications:

The spatial scale and variability of how soils with different textures are naturally distributed needs to be considered prior to segregating different soil textures. It is not practical to segregate different textures if one soil texture encompasses only a small percentage of the total area being salvaged. Segregating soil salvage polygons based on soil texture using AVI maps may not provide the detailed resolution required for proper segregation. Each soil salvage polygon identified from AVI maps may need to be ground truthed prior to salvage operations to determine the actual soil texture.

Adaptive Management:

Segregating upland surface soil by ecosite may be an effective approach. Under certain circumstances similar ecosites may occur on different textured soils (e.g., d ecosite on coarse and fine-textured soils). However, it is unlikely that the SMR and SNR of the undisturbed landscape will be recreated on the post-disturbance landscape. Segregating soils based on ecosites may only be practical when SMR and SNR similar to the "pre-disturbance landscape" are present on the "post-disturbance landscape" and when upland surface soils are directly placed. The SMR and SNR of the post-disturbance landscape need to be considered prior to segregating upland surface soil based on ecosites. This is currently the best available information to preserve diversity of the soil materials for reclamation.

Knowledge Gaps:

There is limited information about the spatial scale at which segregation should occur. Improved techniques to optimize segregation of different textured materials needs to be determined.

STOCKPILING

Background

Stockpiling for short periods of time (e.g., three months) significantly reduces the viability of seeds (Rokich et al. 2000). Research conducted in the AOSR identified that stockpiling upland surface soil into large piles (6 m high) reduced the viability of a large range of boreal plant seeds and roots after eight months of storage. After 8 to 16 months of storage, most seed viability was lost regardless of the size of stockpile constructed (MacKenzie 2011).

Soil Quality: Stockpiling topsoil affects soil chemical, physical and biological properties. Research has identified the following:

- Stockpiling and the associated disturbance from earth-moving equipment increases soil bulk density and reduces aggregate stability causing degradation in soil structure (Hunter and Curie 1956; Abdul-Kareem and McRae 1984).
- Over time, stockpiles become anaerobic below the surface, which negatively affects the biological properties of the soil (Abdul-Kareem and McRae 1984; MacKenzie 2011).
- Stockpiling reduces total nitrogen, available nitrogen and the organic carbon content (Visser et al. 1984; Harris and Birch 1987; Kundu and Ghose 1997).
- Stockpiling causes significant reductions in mycorrhizae populations and other microorganisms (Harris et al. 1989). Mycorrhizae share an important, beneficial relationship with plants, specifically in phosphorus nutrition and water uptake. Some studies suggest that the microbiology of stockpiled topsoil returns quickly once the soil is replaced (Widdowson et al. 1982; Williamson and Johnson 1990).

Some researchers believe that stockpiling makes the soil stagnant and that storage depth and time enhance this effect. Kundu and Ghose (1997) determined stockpiled topsoil in the eastern part of Bihar, India, has a shelf life of seven years. While stockpiled topsoil becomes stagnant from a biological perspective, (specifically for aerobic microorganisms, seeds and roots), there is little evidence to suggest that soils stockpiled in cool climates are stagnant from a nutrient perspective. Abdul-Kareem and McRae (1984) showed large increases in the concentrations of extractable phosphorous, iron, ammonium and manganese with increasing storage depth in stockpiles. Similar results were found in the AOSR from research on upland surface soil. MacKenzie (2011) found that stockpiling upland surface soil for 16 months did not substantially alter the total percent nitrogen or organic matter; however, there was a slight trend for percent organic matter to decrease within smaller stockpiles. The majority of available nutrients (ammonium, phosphorous, potassium) and soluble ions (calcium, potassium and magnesium) increased with storage depth and time. Stockpiling effects within the AOSR have only been studied for a short period of time and long-term data will be required to make stronger conclusions about the changes to soil quality over time.

The effect of stockpiling on the soil quality of peat has not been extensively researched. Kong et al. (1980) examined the physical and biological properties of stockpiles constructed from peat and peat-mineral mixes in the AOSR. Their findings suggested that stored peat nutrient contents are similar to undisturbed peat, and that variances in nutrient or organic carbon levels are the result of admixing with mineral soil. However, incorporating mineral soil in stockpiles may increase peat decomposition through changes in thermal and chemical properties. Stockpiling peat may also reduce the number of mycorrhizae (Danielson et al. 1983). More research is required to identify construction methods that minimize the negative effects of stockpiling on peat.

Researchers generally agree that the changes occurring in stockpiled topsoil include reductions in soil mycorrhizae and other aerobic microorganism populations and a shift in nutrients from the exchangeable to available form. It is believed that the stockpiling effect (rapid changes in the biological and chemical properties of soil) is limited to reclamation materials that are enriched with organic carbon, such as upland surface soil, transitional soil and peat. Despite its altered biology and the loss of seed and root viability, stockpiled soil is a valuable reclamation material.

Managing Stockpiles: Revegetating stockpiled upland surface soil could be difficult. Compared to directly placed upland surface soil, stockpiled upland surface soil will have a significantly reduced viable propagule pool and fungal and microbial population (depending on how stockpiles are managed). Stockpiled upland surface soil will require seeding, transplanting or direct placed upland surface soil applied on top for revegetation. The replaced stockpiled soil may need to be inoculated with microorganisms to help replenish the soil. Additionally, it is unknown how much of the available forms of nutrients will be lost to leaching or volatilization, uptake by plants or fixed back into exchangeable and non-exchangeable forms.

Another practice that can help preserve the viability of propagules in upland surface soil involves periodic removal of the upper surface layer of the stockpile, allowing enough time between each extraction period for the stockpile to revegetate naturally. During each re-salvage event, some of the upper layer is left on the surface of the stockpile. This residual soil contains viable propagules used for revegetating the stripped area. Newly established plants rebuild the propagule bank near the surface, creating another opportunity for salvage. Constructing stockpiles to create a propagule source involves repeated salvage of the top 1.0 m of stockpiled soil. To minimize soil quality degradation, appropriate equipment must be used and the timing of salvage events needs to be considered. The time intervals between each re-salvage period vary from 3 to >5 years. The key factors affecting revegetation success include: the type of ecosite from which the upland surface soil was salvaged; the amount of residual soil that is left on the new surface; the season re-salvage activities occur; compaction; surface roughness; adjacent weed seed sources; and weather. This practice has not been attempted in the AOSR; however, in theory a properly managed permanent stockpile could act as a propagule source.

STOCKPILING

BMP 10 Segregate stockpiles by reclamation material type.

Rationale

Reclamation materials differ in particle size, organic matter content and nutrients. The inherent value of selectively stockpiling reclamation material based on texture and fertility is a major factor affecting water and nutrient dynamics of a reconstructed soil.

Current Practice/Strategy:

Based on the most recent EPEA approvals (issued in 2007), operators are required to minimize mixing of upland surface soil with organic soil, subsoil or suitable overburden. In addition, operators are required to minimize the mixing of different soil textures (fine and coarse) for both upland surface soil and subsoil.

When upland surface soil, peat, peat-mineral mix and subsoil are salvaged with no permanent placement area available, the materials are stockpiled for future use. Upland surface soil and subsoil are typically separated based on soil texture; however, operators with older EPEA approvals segregate upland surface soil based on ecosite. Upland surface soil from a/b ecosites are segregated from the other remaining ecosites that develop on upland surface soil. Operators also stockpile peat and peat-mineral mix separately from upland surface soil and subsoil. If peat is salvaged separately from underlying mineral soil, a separate stockpile of mineral soil might be created for future mixing with peat to create a peat-mineral mix.

State of Knowledge:

Soil Texture**:** Refer to BMP #9 for details about the value of segregating coarse- from fine-textured material.

Organic Matter and Nutrients**:** The organic matter and nutrient content varies between different types of reclamation material. The amount of variation among similar reclamation materials will depend on the ecosite, soil texture and salvage depth. Generally, the amount of organic matter contained within each type of reclamation material is:

peat > peat-mineral mix > transitional soil ≥ upland surface soil > subsoil ≥ suitable overburden

The nutrient value of each type of reclamation material can be categorized in various ways depending on the nutrient being evaluated. Typically, reclamation materials can be categorized based on the value with respect to macronutrients:

upland surface soil = transitional soil > peat-mineral mix > peat > subsoil ≥ suitable overburden

Material Balance Requirements: To meet life of mine material balance requirements operators stockpile reclamation materials. To meet multiple reclamation objectives, operators segregate different types of reclamation materials.

Management Implications:

Available space tends to be limited. Finding enough available space to segregate different reclamation materials can be difficult.

Adaptive Management:

At a minimum, stockpiles should be segregated into five categories:

- Coarse-textured upland surface soil,
- Fine-textured upland surface soil,
- Coarse-textured subsoil,
- Fine-textured subsoil, and
- Peat-mineral mix.

Operators should stockpile transitional soils with upland surface soils. When transitional soils are stockpiled, they have characteristics more in common with stockpiled upland surface soil than a peat-mineral mix. The thicker organic layer present in transitional soils provides additional organic matter to the upland surface soil; however, this does not compromise the physical soil properties as much as a peat-mineral mix. If upland surface soil stockpiles are unavailable for transitional soil storage, they should be stored in a peat-mineral mix stockpile.

Additional categories of segregation may be necessary. The amount of segregation depends on the reclamation objectives. For example:

- If the upland surface soil from a/b ecosites is used to recreate a/b ecosites on post-disturbance landscapes then operators should segregate a/b ecosites into a separate stockpile.
- Transitional soil should not be stockpiled with upland surface soil from a and b ecosites.

- Stockpiles that are managed to sustain propagule viability should be separated from other stockpiles.

Knowledge Gaps:

No knowledge gaps have been identified.

Image 12. Larger stockpile under construction.

STOCKPILING

BMP 11 Integrate reclamation material stockpile locations into the mine planning process.

Rationale

The locations of stockpiles, for all types of reclamation material, need to be considered so that the full range of reclamation materials is available when placement areas are available. Integrating stockpile location and design into the mine planning process should ensure that stockpiles are not moved during the life of mine except for reclamation purposes. Stockpile locations should be situated close to future placement areas to minimize costs of transporting reclamation materials.

Current Practice/Strategy:

Stockpile locations are strategically placed near landforms that require reclamation or in areas that minimize haul distances. When space requirements are limited, reclamation material is stockpiled where space is available.

State of Knowledge:

Having reclamation material available when permanent reclamation areas are available is necessary to meet reclamation objectives. Strategically designating space in the mine lease for stockpiles can minimize placement of reclamation materials at incidental locations.

Management Implications:

Planners may find it difficult to find stockpile locations that do not interfere with mine operations or cause potential environmental problems (e.g., sedimentation into streams or buffer riparian areas). Some mine leases have little space available for long-term reclamation material stockpiles because the leases are so rich with ore. This is a significant challenge for planners. Although not ideal, when space is unavailable, operators may construct temporary stockpiles. These stockpiles can be moved to a more permanent location when space is available. It is important to note that re-handling soils degrades soil physical properties and is more costly.

Adaptive Management:

Stockpile locations should support reclamation processes and protect the surrounding environment. The location of stockpiles across the mine must provide access to all categories of reclamation material required for soil covers identified in the life of mine closure plan. As much as possible, stockpiles should be constructed in permanent locations to minimize the handling of soils. One strategy that may reduce haul distances is to designate stockpile locations in each of the four corners of the lease. Proper water management needs to be in place to prevent sedimentation from runoff into adjacent streams, to buffer riparian areas and to prevent water accumulation at the base of the stockpiles.

Knowledge Gaps:

No knowledge gaps have been identified.

STOCKPILING

BMP 12 Stockpile upland surface soil at well-drained locations.

Rationale

Stockpiling upland surface soil on well drained areas helps preserve soil quality.

Current Practice/Strategy:

Refer to BMP #11 for details about current practice and strategy for stockpile locations.

State of Knowledge:

Stockpiling upland surface soil on areas that are poorly drained will further degrade the physical and chemical properties of soil because of poor aeration and re-handling of wet soils. Poor soil aeration causes soils to become anaerobic. Anaerobic conditions in soil affect organic matter and nutrient dynamics, and if anaerobic conditions are prolonged the long-term productivity of the soil can be affected. Detrimental effects of anaerobic conditions include loss of nitrogen by denitrification, and production of organic acids, H_2S and perhaps other plant toxicants (e.g., ethylene) (Tiedje et al. 1984; MacKenzie 2011). Under anaerobic conditions, the redox potential in the soil decreases and certain trace elements become more soluble. The negative effects of handling wet soils are described in BMP #22.

Management Implications:

Management implications are similar to those described in BMP #11.

Adaptive Management:

Locate upland surface soil stockpile locations on high ground, on areas that are adequately drained or on areas that have been drained prior to stockpiling.

Knowledge Gaps:

No knowledge gaps have been identified.

STOCKPILING

BMP 13 Salvage upland surface soil at stockpile locations that are not designated as upland surface soil stockpiles.

Rationale

Upland surface soil is a valuable reclamation material and must be conserved.

Current Practice/Strategy:

EPEA approvals require upland surface soil salvage. The approval requirements indicate that other reclamation materials cannot be placed on, or mixed in with, upland surface soil. Operators salvage upland surface soil at stockpile locations that are not designated as upland surface soil stockpiles prior to stockpiling other reclamation materials at these locations.

State of Knowledge:

Refer to BMP #4 for details about upland surface soil salvage.

Management Implications:

Salvaging upland surface soil under stockpiles designated for other reclamation materials increases the amount of upland surface soil for reclamation. With increased stockpiling activities taking place as the disturbance extents increase in the AOSR, it is important that operators salvage this resource for use in reclamation. Failure to salvage the upland surface soil in these areas may result in the loss or degradation of this material upon removal of the stockpile.

Adaptive Management:

Upland surface soils can be stockpiled on areas that have upland surface soil.

Knowledge Gaps:

No knowledge gaps have been identified.

STOCKPILING

BMP 14 Use suitable overburden materials to create access roads or to pad peat and peat-mineral stockpiles or in situ peat areas.

Rationale

Peat and peat-mineral mix are valuable reclamation materials. Mixing unsuitable overburden with peat or peat-mineral mix reduces the quality of the reclamation material.

Current Practice/Strategy:

Operators use overburden for padding and to construct ramps to improve trafficability on peat-mineral mix stockpiles. The amount of overburden required depends on the size of the stockpile, air temperature and the moisture content of the peat-mineral mix stockpile. The type of overburden used usually depends on what is nearby and available. On wet or soft ground, overburden that is coarse-textured or has a high gravel and rock content is preferred.

State of Knowledge:

Padding material needs to be stable and provide enough traction to prevent haul trucks from sinking or slipping. Ramps and access roads need to be constructed with material that is capable of providing year round access.

Management Implications:

Using overburden that is physically and chemically suitable for reclamation and padding can be costly when the haul distances are long.

Adaptive Management:

Using good and fair quality (in terms of chemistry) suitable overburden ensures that the chemistry of the peat and peat-mineral mix is not negatively affected. Soil texture should not be used to evaluate the suitability rating of overburden that will be used to construct access roads. Preference should be given to suitable overburden that has a low gravel and rock content where possible.

Knowledge Gaps:

No knowledge gaps have been identified.

STOCKPILING

BMP 15 Construct geotechnically stable, non-erosive stockpiles and control weeds as per relevant regulations.

Rationale

Stockpiling is essential to successful mine planning and reclamation. Properly constructed stockpiles can help maintain soil quality on and off-site by preventing stockpiled soil from eroding. Various methods can be used to maintain a viable propagule bank of locally common boreal plant species. Controlling weeds prevents the spread of unwanted plant species.

Current Practice/Strategy:

EPEA approvals regulate stockpile construction, and the ERCB may also have some oversight. Current EPEA approvals require operators to:

- Construct geotechnically stable structures and slopes with minimal erosion;
- Prevent or mitigate the presence of weeds as designated in the *Weed Control Act* (Government of Alberta 2008) and *Weed Control Regulation* (Government of Alberta 2010);
- Re-contour final slopes to be no steeper than 3 horizontal to 1 vertical (18°) over the total height of any engineered structure; and
- Minimize the loss of plant propagules in upland surface soil.

Operators construct stockpiles on stable ground. For each type of reclamation material, stockpiles are constructed in large, single piles (often higher than 8 m). Multiple piles of one type of reclamation material are constructed throughout the mine. The dimensions of stockpiles are determined by the space available for storage and the amount of reclamation material that needs to be stored. Stockpiles constructed from upland surface soil or peat-mineral mix are left to revegetate by natural recovery from in situ propagules.

State of Knowledge:

Stability and Erosion Control: Stockpiles should be selectively placed on stable areas (not disturbed), and protected from wind and water erosion (Ghose 2001). Slopes should be no steeper than 3 horizontal to 1 vertical to minimize soil erosion. Stockpiles should be vegetated with desired species to prevent erosion.

Weed Control: Weeds on stockpiles should be controlled as per the *Weed Control Act* (Government of Alberta 2008) and the *Weed Control Regulation* (Government of Alberta 2010). Viable weed seeds at the surface of or inside stockpiles can lead to severe weed invasions when the soil is placed in reclamation areas (Hargis and Redente 1984). Residual herbicides should not be used to control weeds as they may degrade soil quality.

Soil Quality: Stockpiles should be selectively placed on areas protected from saturation, unnecessary compaction and contaminants, which reduce soil quality (Ghose 2001). Stockpiling wet soils results in increased soil degradation (Anderson et al. 1988; MacKenzie 2011). Stockpiling effects are not as profound when the stockpiled material contains low amounts of organic matter (e.g., subsoil). For surface soil, storage time should be minimized to prevent soil degradation (Kundu and Ghose 1997; Ghose 2001). Constructing several small stockpiles instead of one large stockpile is better for maintaining the soil quality of surface soils in the long term. Constructing stockpiles of minimum height (1 to 3 m) and maximum surface area can help reduce soil quality deterioration (Thurber Consultants et al. 1990; Ghose 2001; Bell 2004; MacKenzie 2011). Revegetating stockpiles can reduce the loss of beneficial soil microorganisms (Bell 2004). Refer to BMP #17 for further details about the effect of stockpiles on soil quality.

Propagule Viability: After several months of storage, propagule viability in stockpiled surface soil declines significantly below 1.0 m (MacKenzie 2011). Constructing temporary stockpiles (e.g., <1 year) during frozen months prolongs seed viability; however, when stockpiles thaw, seed viability rapidly declines. Constructing stockpiles with minimum height and maximum surface area is the only method that can preserve seed viability when stored for long periods of time (Thurber Consultants et al. 1990; Ghose 2001; Bell 2004; MacKenzie 2011). Stockpiles constructed from upland surface soil may not require seeding because there may be sufficient quantities of desired, native plant propagules (Image 13). Reclamation materials that do not have sufficient quantities of desired, native plant propagules should be seeded.

Image 13. Naturally revegetated windrow of upland surface soil after one growing season.

<u>Management Implications</u>:

Space constraints imposed by site-specific factors generally dictate the size and shape of stockpiles. Operators must consider the trade-offs presented in Table 3 when constructing stockpiles.

Table 3. Stockpile Construction Trade-Offs

Stockpile Size	Soil Quality	Propagule Viability	Material Volume	Space Requirements
Large	↓	↓	↑	↓
Small	↑	↑	↓	↑

Delaying salvage and stockpiling operations until soil moisture conditions are ideal is not practical when handling peat-mineral mix. Refer to BMP #6 for further management constraints associated with peat-mineral mix salvage.

Adaptive Management:

Stability, Erosion and Weed Control: A stockpile that does not have a sufficient propagule bank to revegetate naturally should be seeded with native species that will assist in erosion and weed control. Various plant species respond to edaphic factors; therefore, plant species selected should be suitable for the type of reclamation material stockpiled.

Incorporating excessive amounts of snow can reduce the stability of the stockpile.

Soil Quality: Where practical, wet reclamation material should not be stockpiled. Stockpile construction should occur during winter months; however, operational constraints may dictate the timing of construction. To minimize degradation of upland surface soil, stockpiles should be constructed with minimum height and maximum surface area, given the space available.

Propagule Viability: To preserve the viability of propagules, stockpiles should be constructed with minimum height and maximum surface area, given the space available. Several methods can help maximize the area of upland surface soil stockpiles:

- Construct several small stockpiles versus one large stockpile;
- Construct stockpiles with terraced slopes;
- Free dump upland surface soil at the top of upland surface soil stockpiles instead of smoothing the top out;
- Cap a 1.0 m layer of upland surface soil or free dump upland surface soil on other types of reclamation material stockpiles. Placing upland surface soil on existing stockpiles should only be done if the majority of upland surface soil can be separately salvaged from the stockpiles for placement at a later date.

Proper documentation is required to ensure that the different reclamation materials are properly identified and segregated; and

- Find alternative stockpile locations (e.g., disturbed land, temporary reclamation areas) that allow placement of shallow stockpiles (e.g., <1 to 2 m). This practice is only suitable on areas that do not have a risk of salinization, flooding, prolonged saturation or soil loss to mining activities. In addition, the ground for the stockpile area should be stable and accessible when used for permanent reclamation.

Knowledge Gaps:

Further research is needed to identify construction methods that keep buried seeds viable in upland surface soils. The loss of seed viability is primarily due to microbial respiration and in situ germination. Construction methods that reduce microbial activity may help seeds retain viability for longer periods of time. Currently, the only foreseeable method of maintaining seed viability in stockpiles is to keep stockpiled surface soil frozen until it is required for placement. A practical method of keeping upland surface soil frozen is to salvage upland surface soils under frozen conditions and cap the upland surface soil with a thick layer of peat.

Revegetating stockpiled upland surface soil can be challenging. Compared to direct placed upland surface soil, stockpiled upland surface soil generally has a reduced viable propagule pool and fungal and microbial population. For successful revegetation, stockpiled upland surface soil requires seeding, transplanting or direct placed upland surface soil applied on top. The replaced stockpiled soil may need to be inoculated with microorganisms to help replenish the soil. In addition, it is not known how many available forms of nutrients will be lost to leaching or volatilization, uptake by plants or fixed back into exchangeable and non-exchangeable forms.

The effects of stockpiling on peat-mineral mixes require further research. Although some research has been done on peat-mineral mix stockpiles, the information is limited (Kong et al. 1980). In addition, this research has only assessed the upper 2 m of stockpiles and not the majority of stockpile material that is located deeper than 2 m.

Image 14. Free dumped upland surface soil on the top of a larger stockpile of upland surface soil.

Photographs taken two months into the first growing season.

STOCKPILING

BMP 16 Document stockpile properties.

Rationale

Numerous stockpiles of various reclamation material types can result from life of mine salvage operations. Properly identifying stockpiles is critical to ensure the properties of the stockpiled reclamation materials are documented and to ensure the stockpiles are not mistakenly used or degraded during mine operations. Documenting the locations, properties and management methods of each stockpile is necessary for effective materials handling, mine reclamation planning and for determining reclamation material balances.

Current Practice/Strategy:

Stockpiles can be comprised of materials that originate from large disturbance extents. Similar reclamation material from numerous locations may be mixed together in one stockpile. The location, salvage source, soil quality, type of reclamation material and volume of stockpiles is documented. In addition, signage is typically placed on each different type of stockpiled reclamation material for identification purposes.

State of Knowledge:

Mine operations in the AOSR have developed identification protocols for groups to be aware of stockpile locations and their characteristics. Techniques that have been used to properly identify stockpiles range from mine development tools (computer software programs and databases) to field identification marking tools (signage, tags, etc.).

Management Implications:

Documenting stockpile properties provides historical records of available reclamation materials and provides QA/QC of the type of materials present in stockpiles and available for reclamation.

Adaptive Management:

Properly managed stockpiles should include the following documentation:

- location of stockpiles;
- reclamation material type;
- soil quality;
- construction methods;
- salvage locations;
- volume;
- identification methods; and
- weed control methods.

This information is necessary for mine reclamation planning. Signs should identify the reclamation material type, year of construction and any deviations from normal construction practices (e.g., stockpile used for propagule source or upland surface soil placed on subsoil or peat-mineral mix). Stockpile locations must be identified in mine development software programs and databases for mine planners to integrate into the mine plan so that existing stockpiles are identified and safe from future development.

Knowledge Gaps:

No knowledge gaps have been identified.

DIRECT PLACEMENT

BMP 17 Direct placement is preferred to stockpiling.

Rationale
Direct placement of reclamation materials is preferred to stockpiling because soil quality and structure is better maintained and reclamation costs are reduced. Direct placement of upland surface soil and transitional soil is preferred because seed viability, nutrients, organic matter and soil biota are difficult to replenish or require additional measures once degradation occurs in stockpiles. Direct placement of upland surface soils, transitional soil and the surface of organic soils ensures that viable propagules are preserved and available for revegetation. Direct placement of peat-mineral mix and subsoil should be done when feasible.

Current Practice/Strategy:

EPEA approvals require operators to minimize the loss of viable propagules during mining operations. Operators can achieve this by direct placing reclamation materials containing viable propagules. Direct placement is not always feasible because of a lack of available space for permanent reclamation or because of the additional costs associated with long haul distances.

Reclamation material must be stockpiled in the early years of mine development because landforms have not been fully constructed and are not yet available. As development progresses, and more land is available for reclamation, less soil is stockpiled because there is more opportunity for direct placement of materials. However, developing mines must continue to stockpile reclamation material to meet long-term reclamation materials balances. The storage timeline for stockpiled soil ranges from a few months to several decades.

State of Knowledge:

Propagules: Direct placement of soils containing viable propagules (e.g., upland surface soil, transitional soil, peat and peat-mineral mix) is one of the most economical ways of ensuring the re-establishment of the wide diversity of species that exist in native ecosystems (Leck et al. 1989; Bell 2001). However, if there is a potential for undesirable species in the seed bank (e.g., noxious weeds, competitive native or introduced species) to establish and out-compete desired species, direct placement may not be the best method to achieve reclamation objectives (e.g., commercial forest).

Soil Quality: Soil quality is better preserved when directly placed versus stockpiling. Stockpiling topsoil affects soil chemical, physical and biological properties.

Plant Establishment: There has been no research done in the AOSR that compares directly placed coversoils and stockpiled coversoil with respect to the physical and chemical properties of the coversoil or on plant establishment and plant growth. The majority of research in the AOSR has assessed direct placement of upland surface soil and peat-mineral mix (Lanoue and Qualizza 1999; MacKenzie 2006, 2011; Brown 2010). Direct placement of upland surface soil has resulted in excellent native plant establishment when placed on suitable overburden, both coarse and fine-textured, and peat-mineral mix. However, results from the few studies done in different ecosystems show that directly placed topsoil is better in establishing native ecosystems compared to placing topsoil that has been stockpiled (Tacey and Glossop 1980; DePuit 1984).

Season of Soil Salvage and Tree Harvest: The effects of sprouting in trembling aspen and other boreal deciduous trees are most vigorous when the total nonstructural carbohydrate (TNC) reserves are at their highest levels (Peterson and Peterson 1992; Landhäusser and Lieffers 1997, 2003; Frey et al. 2003). In terms of the timing of harvest, winter logging usually promotes abundant suckering and best growth compared with spring or summer harvest (Peterson and Peterson 1992). The time left between tree harvest and soil salvage can have an effect on the re-sprouting of trembling aspen. MacKenzie (2010) determined that harvesting trees the same fall/winter as the soil was salvaged resulted in significantly greater aspen establishment (14,739 stems/ha vs. 2968 stems/ha) compared to salvaging soils 5 years after tree harvest.

Management Implications:

Logistical constraints, cost and the amount of land available for permanent reclamation at any given time determine when and how much reclamation material can be directly placed. Harvesting trees in the same fall or winter as the soils are salvaged is difficult due to conflicting requirements for pre-development tree salvage operations as well as other time constraints.

Adaptive Management:

Prioritize: When areas are available for permanent reclamation, the material that can be directly placed should be given priority over stockpiled reclamation material. In addition, upland surface soils and transitional soils should be placed on areas ready for permanent reclamation before other reclamation materials to help preserve viable propagules. Prioritizing direct placement of upland surface soil and transitional soil reduces the volume that goes to stockpile. It is important to note that the potential risk for salinization should be determined prior to placing upland surface soils or transitional soils so that they are not placed on areas that would result in a loss of soil quality due to salinity. BMP #18 describes other constraints and risks on placement areas.

Revegetation: The use of upland surface soil and transitional soil as a propagule source is preferred to out-planting or relying on natural recovery from adjacent seed sources. However, if a desired plant species is not present in the soil propagule bank, or does not regenerate well from direct placement, these species may need to be planted. If the objective of using upland surface soil is to maximize deciduous tree establishment during direct placement, it is best to salvage soil shortly after timber is harvested. Timber should not be harvested more than a few months prior to soil salvage and both harvest and salvage operations should occur during fall or winter months to minimize the loss of viable propagules. The risk of deep frost penetration is reduced if the timber is harvested immediately before soil salvage. Timber harvest operations need to be conducted in compliance with the *Migratory Birds Convention Act* (Government of Canada 1994). If trees are cleared during potential nesting periods, bird assessments need to be implemented to verify no nesting birds are present prior to logging.

Operators should look for alternative opportunities to directly place salvaged topsoil, transitional soil and peat-mineral mixes if there are no areas available for permanent reclamation. For example, direct placement of upland surface soil on peat-mineral mix improves the establishment of diverse self-sustaining native ecosystems (Lanoue and Qualizza 1999; Mackenzie 2011). Although this method might seem counterintuitive, research suggests that this is a better alternative to stockpiling. Upland surface soil may be placed on directly placed peat-mineral mix or on older reclamation areas that have received peat-mineral mix. The environmental outcome of placing upland surface soil on areas previously reclaimed with peat-mineral mixes that do not have diverse or productive plant communities established is greater than if placed on areas with peat-mineral mix that have diverse or productive plant communities established. Upland surface soil should not be placed on former reclaimed areas that are or will be prone to soil quality degradation or on areas that would accelerate the loss of viable propagules (e.g., saline areas, saturated or flooded areas). Additionally, placing upland surface soil on substrates that already have a viable propagule bank of species should be avoided.

Ecosite Establishment: To obtain the most value from direct placing transitional soil and upland surface soil, operators should place the reclamation materials on post-disturbance landscapes at locations where the predicted SMR and SNR are similar to the salvage site. This is considered best practice to re-establish targeted ecosites. The dominant and frequent vascular and non-vascular species present in an upland forest and peatland are likely to be present within the transitional area. The selective salvage and direct placement of transitional soil can increase the success of re-establishing these species. The success of species establishment depends on whether the transitional soils were salvaged adjacent to a bog or fen, and how well the new SMR and SNR in the placement area mimics the original donor site conditions. When transitional soils cannot be placed onto an area that has similar SMR and SNR as the pre-disturbance landscape, directly placing onto other upland areas is preferred to stockpiling. Further details on placement are provided in BMP #5.

Placement Strategies: Operators should place upland surface soil in multiple areas throughout the mine site, and away from the edge of the mine lease boundaries, to optimize dispersal of native boreal plant propagules. In addition, operators should consider how direct placed upland surface soil is distributed at a localized scale to enhance native species egress. Establishing diverse, forested stands throughout the mine is expected to enhance seed dispersal from birds and mammals on adjacent reclaimed areas with peat-mineral mix soil covers.

Efforts should be made to maximize the area of post-disturbance landscapes for direct placement. Placing upland surface soil in several small islands may be preferable to placing one large island surrounded by peat-mineral mix because a greater edge to interior ratio will be created. This is desirable because it increases the dispersal of native plant species seeds onto adjacent peat-mineral mixes. However, plants establishing from upland surface soil in very small islands may not successfully establish because they become out-competed by competitive herbaceous plants ingressing from adjacent areas.

Various distribution options are available for placement. The examples presented in Figure 3 show how the same amount of upland surface soil can be distributed. The first option at a localized scale might be the least desirable because the edge to interior ratio is the lowest. The fourth option has the greatest overall edge to interior ratio; however, this option may only be desirable if there is a low risk of adjacent, undesirable plant species ingressing and competing with native plants establishing within the islands.

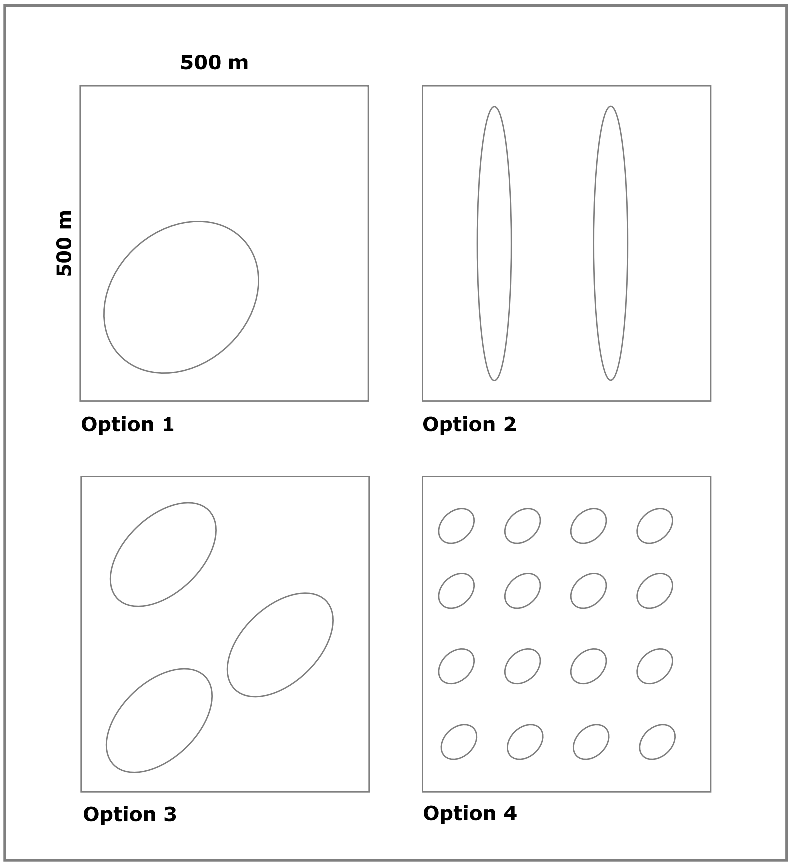

Figure 3. Examples of distribution options for placing upland surface soil.

Factors that should be considered when selecting how upland surface soils are distributed include: reclamation objectives; the volume of upland surface soil available for direct placement; wildlife activity; abundance and composition of plant species in adjacent areas; abundance and composition of plant propagules in the upland surface soil; and wind direction.

Knowledge Gaps:

Managing the abundance and viability of a soil propagule bank has been studied in natural forests; however, research is needed to determine the effects of certain practices on forests that have soils transported from their original location to a new environment. The knowledge gaps identified are listed below.

- Young and mid-seral forests have a more abundant and diverse propagule bank than late seral forests (Moore and Wein 1977; Warr et al. 1993). Harvesting old growth forests years in advance of soil salvage increases the total soil propagule bank; however, the time interval between harvesting and soil salvage (for the purpose of increasing the regeneration success for aspen) needs to be further researched. In addition, a cost-benefit analysis should be completed.

- Wounding aspen roots can increase the amount of suckering (Fraser et al. 2004). Using silviculture practices such as disking or ripping prior to soil salvage can increase the abundance of regenerating aspen suckers on undisturbed soils; however, the effects of these practices have not been studied when soil is directly placed on reclaimed areas.
- On a localized scale, the optimal size for placing individual upland surface soil patches is unknown. Creating small islands may not be desirable if there is risk of losing desirable native species to competitive herbaceous plants ingressing from adjacent reclamation areas. Additionally, placing upland surface soil in one large island may not maximize native plant egress; however, native plant egress should also be evaluated at a landscape level.
- Placing salvaged small plugs of the forest floor layer with the upper Ae horizon adjacent to transplanted trees on areas reclaimed with peat-mineral mix requires assessment. Using plugs from upland soil planted immediately adjacent to planted trees would provide a source of nutrients and mychorrizae for the planted trees, in addition to providing an inoculation of seeds, roots and microorganisms on peat-mineral mixes.

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SOIL PLACEMENT

BMP 18 Identify constraints associated with the landscape when planning soil-cover designs.

Rationale

The three main constraints that determine the land capability to support boreal ecosystems in the AOSR are SMR, SNR and salinity. Understanding these constraints enables operators to:

- Develop soil-cover designs that achieve reclamation objectives;
- Prioritize the placement of upland surface soil, transitional soil and subsoil on areas that will prevent degradation of the soil quality of these reclamation materials; and
- Select reclamation materials and placement areas to achieve target ecosites / site types.

Current Practice/Strategy:

Soil placement in the AOSR has evolved over time. The development of optimal soil-cover designs to support self-sustaining forest plant communities is challenging because of the long time frame required to evaluate how plant communities in the boreal climate respond to different soil-cover designs. The oldest soil-cover designs in the AOSR (approximately 40 years) are considered young from a forest soil development perspective. Operators, government, researchers and consultants are still in the process of gathering information on how past soil-cover designs have influenced plant establishment, soil nutrient cycles, soil biota and chemical transport mechanisms from substrates into reconstructed soil profiles. Continually changing reclamation requirements, expanding scientific knowledge and input from stakeholders will influence prescriptions for soil placement.

Current EPEA approvals include minimum soil placement depths to manage constraints on different landforms. The approvals do not provide guidance on handling different reclamation materials to achieve desired outcomes. The *Land Capability Classification System* (LCCS; Alberta Environment 2006) is used to estimate SMR and SNR on reclaimed sites. These estimates are used to identify target ecosites as well as appropriate species for revegetation (Alberta Environment 2010). They may also be used to design and construct soil-cover designs with specific SMR and SNR.

State of Knowledge:

General: The key determinants affecting plant establishment and growth are the quality of underlying substrate, the annual effective precipitation, and the quality and depth of replaced soils (Hargis and Redente 1984). The quality of soil used for placement should be determined from the soil inventory, the planned end land-use objectives and the impact underlying substrates will have on short and long-term quality of the cover soil. Different types of plant communities are adapted to different soil conditions; therefore, intended soil placement (properties and depths) should correspond to the intended revegetation treatment. Native soils in the AOSR range from moist and nutrient rich to dry and nutrient poor. The objective of reclamation is not to create a uniform reclaimed soil with uniform moisture and nutrient conditions, but a range similar to that found in native soils of the AOSR.

Constraints: Selecting an appropriate soil-cover design requires knowledge of the constraints on the landform, the landscape, the reclamation material and the underlying substrate. An understanding of how the constraints affect the targeted plant community is also required. Three constraints to consider include: SMR, SNR and salinity/sodicity. Barbour et al. (2007) synthesized the majority of information available about constraints and their influence on coversoil quality and reclamation success. Soil moisture regulates soil forming processes, biological activity, solute transport and plant growth. Nutrients contain essential elements required for plant and microbial metabolic processes. Salinity and sodicity negatively affect soil quality, soil microbial activity and plant growth for most boreal species. Managing these constraints at the following three stages: landform, soil cover and revegetation design stages can help operators achieve reclamation objectives.

Factors such as plant species selection, the physical and chemical properties of reclamation material, soil-cover designs and placement depth must be considered when managing constraints. Because SMR and SNR are linked to particular ecosites/site types in revegetation plans, these conditions should not be constraints for establishment of associated vegetation communities (i.e., although a subxeric moisture regime is constraining to establishment of many vegetation communities, it should not be for establishment of dry/poor site types or a or b ecosites). In contrast, salinity/sodicity, where present, is potentially constraining for most reclaimed ecosystems.

The Revegetation Manual (Alberta Environment 2010) explains how constraints limit the revegetation of different site types for various end land-uses. The three constraints noted above are the most typical constraints present on landforms; however, this should not prevent planners from understanding other types of constraints that exist on other types of landforms. These may include: hydrocarbons, sulphur and trace metals.

The flow chart in Figure 4 depicts common constraints associated with different landforms and the more obvious limitations for end land-uses and site types. This figure is primarily conceptual and does not comprehensively represent all of the constraints for every landform, end land-use or site type. For example, Figure 4 indicates that salinity is a constraint for commercial-forest end land-uses only, as the Revegetation Manual states that topsoil EC levels must be below 2 dS/m for commercial forest end land-uses. However, elevated salinity levels may be constraining to successful achievement of other land uses as well.

The figure also assumes that nutrient and moisture constraints are linear in direction and focuses on one end of the spectrum where either could limit site type. In reality, constraints that negatively impact one end land-use or site type might be beneficial to another. For example, a soil cover that has a low SMR and SNR is unsuitable for reclaiming a moist rich site type with a commercial forest end land-use. However, these soil conditions are suitable for creating a dry, nutrient-poor site type with a non-commercial forest end land-use.

Risk: The degree of risk (low, medium, high) a constraint has on the quality of reclamation material (after placement) or on plant growth depends on the type of substrate used to construct a landform, the type of reclamation material placed, the landscape position, the aspect and the plant species. Combinations of the abiotic factors regulate the SMR, which influences the concentrations and flow of nutrients and salts. The levels of risk for moisture and nutrient constraints are not the same for reclamation materials with different soil textures or for different ecosites or site types. A placement area that is projected to be xeric (e.g., upper slope and nutrient poor tailings sand) may be considered high risk for plant communities that require nutrient rich, fine-textured soil (higher soil moisture); however, these conditions pose a low risk for plant communities that require nutrient poor, coarse-textured soil (lower soil moisture). Forecasting the level of risk for each constraint has only been possible through research done on existing landforms within the AOSR. Barbour et al. (2007) synthesized research done in the AOSR on soil moisture, soil salinity/sodicity, soil nutrients and biological response of various reconstructed soils placed on saline/sodic overburden dumps and tailings sand dykes. Their study summarizes the risks associated with reclaiming various types of ecosites using different soil prescriptions and landscape positions on landforms constructed from saline/sodic overburden and tailings sand.

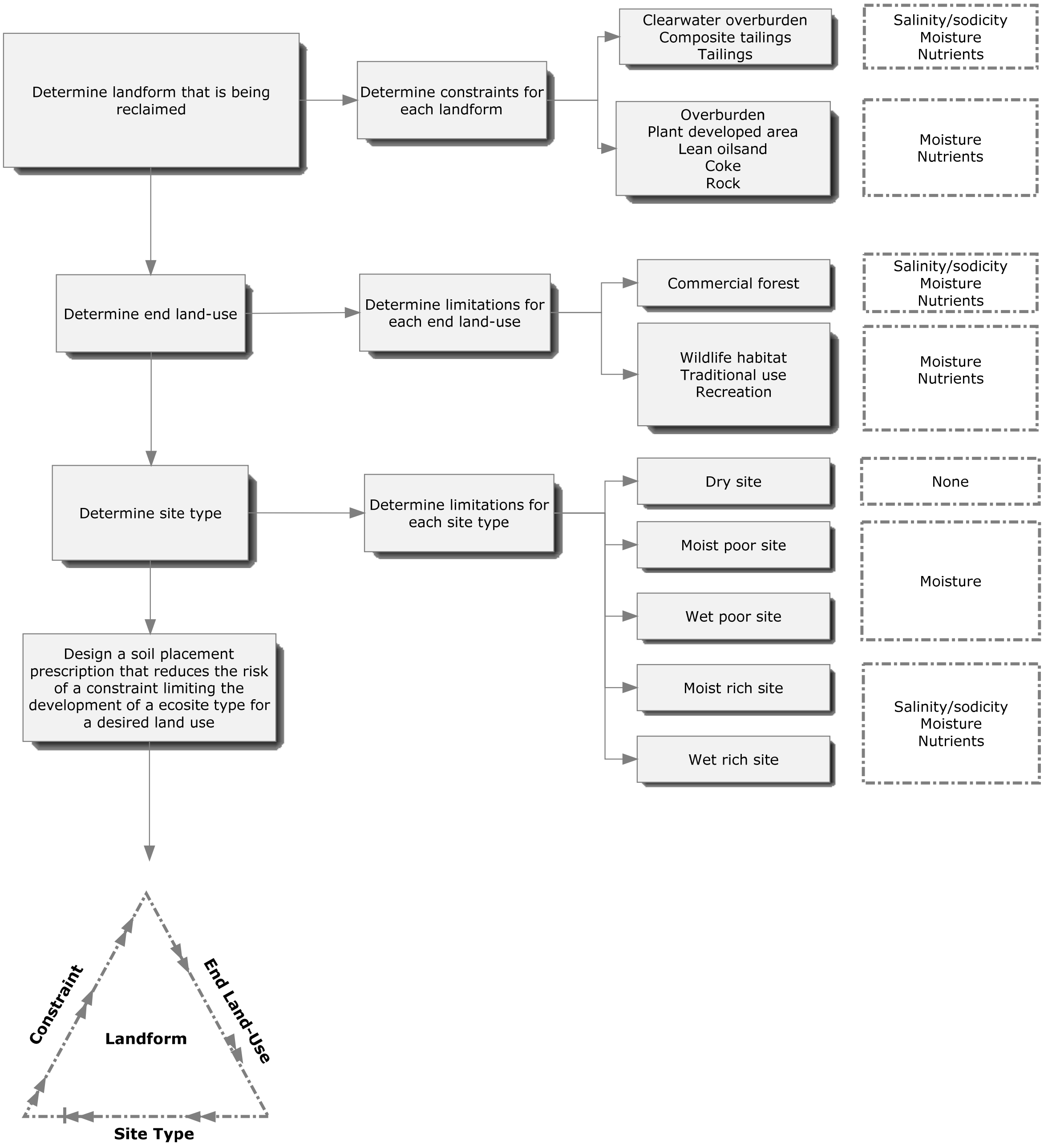

Figure 4. Constraints associated with different landforms and common limitations for different land-uses and site types.

Image 15. Lower slope of a saline sodic overburden substrate displaying a high risk salinity constraint.

The levels of risk associated with various types of constraints for three different landforms are illustrated in Figure 5 for a moist rich site type. This figure considers the interaction of slope position and aspect. A high-risk constraint is more likely to reduce the quality of the reconstructed soil profile and/or limit the net productivity of a plant community. On saline/sodic overburden dumps, the risk for soil salinization is higher on locations where salt flushing mechanisms are inoperative (e.g., discharge areas and toe slopes and flat surfaces). The degree to which salt flushing mechanisms work depends on factors such as the underlying water table and groundwater dynamics, hydraulic conductivity of the material and surface-soil water balance. On tailings sand dykes, the risk for soil salinization is high in areas where water seeps (lower and toe slopes, and benches). As previously mentioned the degree of risk for SMR and SNR is ecosite/site type dependent, but is more universal for salinity constraints.

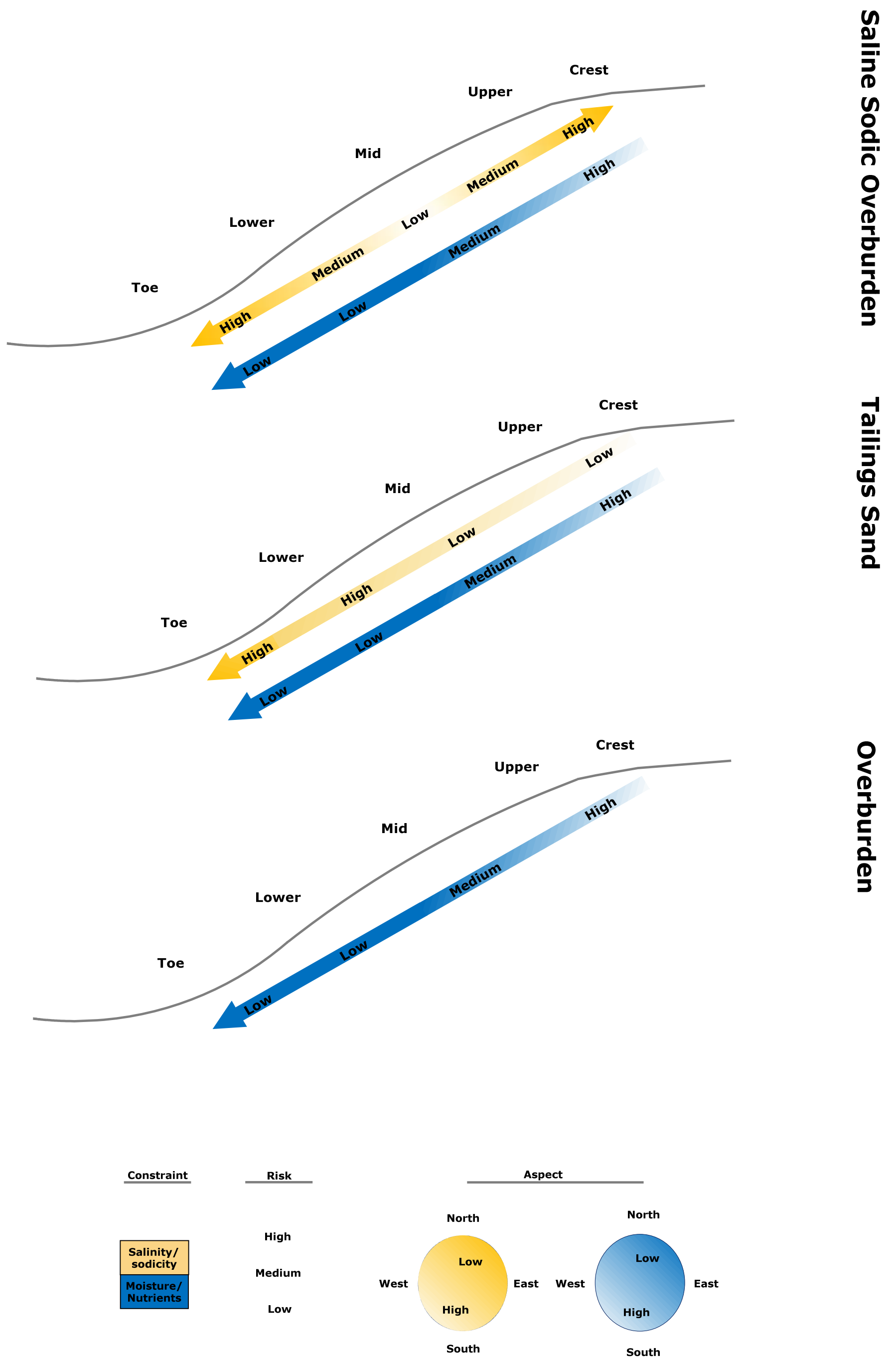

Figure 5. Illustration depicting various constraints and the different levels of risk associated with three different types of landforms.

Coversoil Designs: Soil-cover designs are typically influenced by a combination of:

(1) Reclamation objectives (e.g., desired reclaimed vegetation communities and end land-uses); and
(2) Operational constraints (e.g., mine planning and material balances).

Within this context, soil-cover designs may be either:

(1) Developed for use on existing or designed landforms, to best achieve reclamation objectives on these landforms (this scenario is called the “Site-Type Approach” in the Revegetation Manual); or
(2) Developed in conjunction with landform/landscape design, as part of an integrated design to best achieve reclamation objectives on these landforms/landscapes (this scenario is called the “End-Land-Use Approach” in the Revegetation Manual).

Although the “Site-Type” and “End-Land-Use” scenarios are presented as separate approaches in the Revegetation Manual, they are in fact highly related, and it is assumed that most soil-cover design will be iterative, and share characteristics of both approaches. Both approaches can make use of two fundamental premises of soil-cover design for reclamation:

(1) That soil covers can be designed to address and mitigate or take advantage of potential constraints in order to achieve desired outcomes; and
(2) That diversity (and diverse constraints) will result from variation (both designed and non-designed) in underlying topography and in soil placement, and that this diversity and these constraints are both:
    a. Opportunities for the creation of diverse reclaimed landscapes; and
    b. Capable of being incorporated and addressed in revegetation design.

Regardless of which of the above approaches is primarily used, best management practice for soil-cover planning will involve evaluation of available soil-placement options (material selection, depth of placement, layering) with reference to constraints (material availability, logistics and landform/landscape-level constraints), and matched to objectives (risk reduction and desired reclamation vegetation communities and end land-uses), to produce an integrated design.

Management Implications:

Operational changes to mining activities that result in changing landscape constraints makes it difficult to design reclamation activities. As a result, operators may be forced to deviate from optimal plans.

Adaptive Management:

Prioritization: Operators should decide whether risks preclude placement of upland surface soil or subsoil, and transitional soil at locations characterized by specific constraints. Efforts should be made to avoid placing these reclamation materials on areas that pose a high risk to salinization. Such efforts would include creating access points to place peat-mineral mix and suitable overburden on areas with high-risk salinity constraints. This enables operators to place better quality reclamation material on lower risk constraints. The following components should be taken into consideration for constraints that may limit reclamation objectives:

- Types of reclamation material and volumes available for placement;
- Types of soil-cover designs that will be used;
- Types of constraints associated with the landform, landscape and reclamation material;
- The level of risk each constraint has on the quality of the reclamation material after placement; and
- The targeted ecosites/ecosite phases to be reclaimed.

Moisture and Nutrient Constraints: Moisture and nutrient constraints should be interpreted relative to the desired outcome. It is not assumed that more moisture equals “good” or that less nutrients equals “poor.” Information about the physical and chemical properties of a reclamation material can help operators manage nutrient and moisture constraints that effect the establishment of target ecosites.

To enhance soil moisture or nutrient availability and retention, it is considered best practice to increase the placement depth of reclamation materials; layer different types of reclamation materials with different hydraulic conductivities; and apply fine-textured reclamation materials.

To enhance soil nutrient availability and retention, it is considered best practice to directly place reclamation material; use reclamation materials that contain higher concentrations of available and total nutrients; use fine-textured reclamation materials; and apply fertilizer when necessary.

Knowledge Gaps:

The effect that landform design has on moisture, nutrient and salinity constraints is not fully understood. Current soil-cover designs disregard relief and contouring as factors to be used to manage these constraints. Research is underway to improve understanding of how soil placement prescriptions affect the long-term sustainability of plant establishment, nutrient cycles, soil biota and salt ingress on landforms constructed from various types of substrates (e.g., saline/sodic overburden, tailings sand, composite tailings, coke, sulphur and lean oil sands).

The placement depths of different types of reclamation materials require additional research to determine their effectiveness at controlling salinity, moisture and nutrient constraints. The placement depth of overburden required to control salinity constraints on tailings dykes, consolidated tailings and saline/sodic overburden substrates needs further evaluation. How these landforms impact the long-term quality of reconstructed soils is unknown.

SOIL PLACEMENT

BMP 19 Use appropriate reclamation material to meet objectives.

Rationale
A soil-cover design should provide a soil cover that can support a self-sustaining ecosystem. A soil-cover design needs to supply plants and soil biota with nutrients, water and a hospitable environment for growth. Some factors that influence the availability and storage of nutrients and water are the type of substrate used to construct a landform, the reclamation material, the plant community and the landscape position. These factors also influence the movement of potentially harmful substances from substrates into the rooting zone.

The types of reclamation materials used, and the order in which they are placed within soil-cover designs, will depend on reclamation objectives and the target plant community to be revegetated.

Salvaged reclamation materials used in soil-cover designs include:

- Upland surface soil (coarse and fine);
- Transitional soil;
- Peat;
- Peat-mineral mix;
- Subsoil (coarse and fine); and
- Suitable overburden.

Current Practice/Strategy:

EPEA approvals require operators to place soil covers that provide similar land capability classes to pre-disturbance land capabilities. The approvals also require operators to describe how salvaged reclamation materials will be used to achieve reclamation objectives. Soil-cover design requirements vary among operators, because each mine is composed of different land capabilities and has different types of reclamation material and different types of substrate materials requiring reclamation.

Reclamation materials are often used in combinations and are layered to provide a soil-cover design. Soil-cover designs generally have a coversoil and a reconstructed subsoil layer. Coversoils are reclamation materials that provide enriched amounts of organic matter and nutrients and include any of the following reclamation materials: upland surface soil, transitional soil, peat-mineral mix or peat alone. Reconstructed subsoil layers include at least one of the following: suitable overburden, tailings sand or subsoil. Peat-mineral mix placed over suitable overburden and/or tailings sand are the most common soil-cover designs in the AOSR.

When upland surface soil is used as a coversoil it is typically placed over suitable overburden. For a detailed description of historical and current soil placement prescriptions refer to the *Comprehensive Report on Operational Reclamation Techniques in the Mineable Oil Sands Region* (Macyk and Drozdowski 2008).

Operators use the LCCS (Alberta Environment 2006) to facilitate evaluation of land capabilities for forest ecosystems on pre-disturbance and reclaimed lands. Some operators use the LCCS to design soil covers prior to soil placement. The Revegetation Manual (Alberta Environment 2010) directs operators to utilize the LCCS in the development of an appropriate soil-cover design to reclaim similar ecosystem structure and function to that of native plant communities.

State of Knowledge:

The distribution of reclamation materials within a soil-cover design should be based on reclamation objectives. The utility of a particular reclamation material to contribute to achieving reclamation objectives depends on its availability/abundance and chemical, physical and biological properties. The more detailed discussion of the importance and quality of specific reclamation materials available in the AOSR is provided in earlier BMP sections of this document.

The LCCS guides operators in selecting reclamation materials to create soil-cover designs to achieve a particular land capability. The LCCS is not an exact model, but a tool to assess the general land capability of the soil. While the LCCS has been fairly accurate at predicting SMR, it does not predict SNR as accurately (Barbour et al. 2007). Creating native ecosystems requires knowledge of the complex interactions between abiotic and biotic factors. The LCCS and other available models (e.g., FORECAST) are not sophisticated enough to accurately predict how various reclamation materials should be placed to support a plant community with similar ecosystem structure and function with that of native plant communities.

The best results in reclaiming native ecosystems may be achieved when separated reclamation materials are placed back in the original sequence they were salvaged (DePuit 1984; McSweeney et al. 1987; Bell 2004). Sequential replacement of surface soil over subsoil has been controversial. This is because of the soil compaction created from additional equipment movement and the logistical challenges associated with depositing the first-salvaged, uppermost horizons last during topsoil application. Furthermore, underlying substrates which are either not present in the pre-disturbance (e.g., by-products such as tailings sand or coke), or are present at greater depths (overburden), may ultimately be the key factor determining the land capability of a reclaimed landscape. In this case, more complex soil-cover designs intended to improve reclamation performance may have no positive impact to soil reclamation. Assessing the suitability of replacing soil layers sequentially (as found in pre-disturbance conditions) on a post-disturbance landscape and the relative impact of underlying substrates to reclamation performance requires further evaluation.

Image 16. Placement of upland surface soil from an a ecosite on a peat-mineral mix substrate.

Image 17. Natural revegetation of native plants from propagules contained in upland surface soil salvaged from an a ecosite.
The soil was placed to a depth of 10 cm on top of a peat-mineral mix. The photo was taken in the second growing season.

Management Implications:

Predicting the SMR and SNR on recently constructed landforms that do not have a developed water table can be difficult. As a result, operators may not be able to accurately predict the SMR or SNR for a range of different soil-cover designs that would allow for optimal distribution of the available reclamation materials. Soil quality conditions of substrates may not be static and go through slow to rapid changes post-reclamation. The impact of these changes to reclamation make it difficult to assess and assume conditions will remain the same or change with time.

Adaptive Management:

General: Reclamation materials should be prioritized for use in soil-cover designs that achieve reclamation objectives. The soil physical, chemical and biological properties should be selected to support the desired plant community. The principles outlined in the Site-Type approach (see BMP #18) should be applied when constructing soil-cover designs that target the creation of natural ecosites/site types and for controlling risks for various constraints.

Ecosite Establishment: When reclaiming to a natural ecosystem, it is best to design soil covers with soil layers that have similar physical and chemical properties. For example, a soil-cover design consisting of upland surface soil and transitional soil should be placed over subsoil from similar ecosites. Descriptions of general physical and chemical properties of natural soil profiles for various ecosites are presented in *The Field Guide to Ecosites of Northern Alberta* (Beckingham and Archibald 1996).

Substrate: Substrate quality may have an impact on reclamation performance. Marginal substrates require additional soil-cover design depths and/or more complex soil-cover designs (multiple placement lifts).

Prioritization: A greater environmental outcome may be achieved if various reclamation materials are placed as follows (in order of prioritization):

(1) Use subsoil when soil-cover designs include upland surface soil and transitional soil;
(2) Place upland surface soil and transitional soil over suitable overburden or tailings sand when no subsoil is available;
(3) Place peat-mineral mix over subsoil when extra subsoil is available; or
(4) Place peat-mineral mix over suitable overburden or tailings sand when subsoil is unavailable.

Knowledge Gaps:

There is no model developed that accurately demonstrates if ecosystem structure and function of reclaimed sites converges with that of native sites in the AOSR. More research is required on the impact of complex soil-cover designs (multiple lifts) and of substrate quality on reclamation performance (see Knowledge Gaps in BMP #18). Measuring reclamation performance at various times during post-reclamation to assess long-term performance trajectories may help better refine existing predictive models or develop new models that are more accurate.

SOIL PLACEMENT

BMP 20 Place an adequate depth of material to separate coversoils from substrates of marginal soil quality.

Rationale

A minimum depth of material is required over substrates with marginal soil quality to create a buffer between unsuitable material and suitable material. This helps support plant growth and achieve reclamation objectives.

Current Practice/Strategy:

EPEA approvals require operators to place a minimum depth of 1.0 m of suitable overburden or tailings sand on substrates such as: lean oil sands, rock, rejects from the oil sands conditioning and transport system, consolidated tailings, Clearwater overburden, material from processing plant areas and coke. Operators typically place a minimum of 1.0 m of subsoil and suitable overburden over these substrates. Tailings sand may be used as a substitute for suitable overburden.

The minimum capping depth over substrates with marginal soil quality is different for different mines. The minimum capping depth varies among operators because their approvals are from different time periods that were based on the best available information at the time. The *Comprehensive Report on Operational Reclamation Techniques in the Mineable Oil Sands Region* (Macyk and Drozdowski 2008) provides more information.

State of Knowledge:

The thickness of the replaced soil depends on multiple factors including: the quality of the overburden to be covered, the annual average effective precipitation, soil quality, topographic position and species requirements (Hargis and Redente 1984; Merrill et al. 1998). Where the underlying substrate material has adverse characteristics for root growth, the depth of soil replaced (which must be applied to achieve long-term productivity) depends on the nature and severity of the substrate material. Soil placement depth requirements generally increase as the severity of the adverse properties of the substrate material increase (Hargis and Redente 1984). It is important to note that when replacing a considerable depth of soil, compaction is one of the key factors limiting plant productivity (Bell 2004). The increased traffic and/or soil handling required to replace thicker depths can increase compaction and limit root growth.

Barbour et al. (2007) summarized research done in the AOSR to assess effects of soil capping depths on plant growth, soil quality, and salt movement on saline/sodic overburden and tailings dykes. The information provided by Barbour et al. (2007) does not specify a minimum capping depth; however, the document indicates that the most conservative soil reconstruction scenario would be to include the placement of 30 cm of coversoil over 50 to 70 cm of suitable mineral soil over tailings sand and/or saline/sodic overburden.

Research in other regions suggests that greater soil placement depth results in increased plant productivity on saline/sodic overburden and acidic overburdens; however, the minimum thickness required can depend on topography (Barth and Martin 1984; Merrill et al. 1998). In Australia, Bell (2004) recommended no more than 2.0 m thickness of non-toxic overburden or substrate material be applied to adverse material; and 1.0 to 2.0 m should be placed over saline/sodic overburden. Barth and Martin (1984) show that different soil depths are required on different types of overburden to obtain maximum vegetation production in the Northern Great Plains. Soil depths of 50 cm were required on generic spoil (non saline, non-sodic and non acidic), 71 cm for sodic spoil, indeterminate depths on acid spoil and 0 cm on soil-like spoil. Merrill et al. (1998) stated that soil replacement thickness could be less on side slope and lower landscape positions to achieve a given level of soil productivity.

Management Implications:

Placement of thick capping depths can be difficult to achieve if there is limited availability of reclamation material. Planning for long-term availability of suitable overburden can be challenging, and in some cases, stockpiling of suitable overburden to meet future demands may need to be considered.

Adaptive Management:

Landforms should be developed in such a way that the substrate has undergone a measure of segregation where the poorer quality material is targeted to placed further away from active portion of the environment. Place poorer quality substrates at greater depths, further away from the plant root zone and surficial water table. This technique may improve reclamation performance and/or improve the capability of poorer quality soil-cover designs to meet reclamation objectives.

Knowledge Gaps:

There is a lack of available information regarding minimum capping depths for substrates other than saline/sodic overburden and tailings sand. In addition, the effects that slope position and aspect have on minimum capping depths are not well understood.

SOIL PLACEMENT

BMP 21 Place a sufficient depth of reclamation material to support a rooting zone and tree cover and to achieve reclamation objectives.

Rationale

A sufficient depth of reclamation material is needed to provide support for roots and sufficient storage of water and nutrients to sustain boreal forest plant communities.

Current Practice/Strategy:

EPEA approvals require operators to place a minimum depth of coversoil over suitable overburden and tailings sand. Operators typically place between 0.1 to 0.5 m of coversoil over suitable overburden and 0.2 to 0.5 m of coversoil over tailings sand. The LCCS provides operators a tool to help determine placement depths of coversoil (Alberta Environment 2006).

State of Knowledge:

For most trees in the boreal forest, the majority of roots are found within <1.0 m of the soil surface. On many sites, the majority of fine roots lie in the upper 0.2 to 0.3 m of the soil (Fisher and Binkley 2000); however, rooting depth and root distribution is dependent on soil physical and chemical properties and varies with plant species. In most cases, rooting depth is shallower in fine-textured soil versus coarse-textured soil (Strong and La Roi 1983; Barbour et al. 2007).

The effect that coversoil placement depth has on supporting plant communities depends on a number of factors including the quality of substrate on which it is placed, plant species, annual precipitation and topographic position. The most important factors to consider are those that have the greatest influence on plant community establishment, soil water storage and availability, and nutrient availability and storage capacity. Recommending a few standard placement depths to be used over a wide range of available reclamation materials is not an effective way of redistributing coversoils. In addition, uniform placement depths of soil over an entire landform may impede the development of a diverse plant community across a reclaimed landscape (DePuit 1984).

The optimal placement depth required to sustain a mature, productive forest may be different than the depth required for a diverse wildlife habitat. The most important considerations for forest productivity are: available soil moisture and growing space for tree roots (Bussler et al. 1984; Torbert et al. 1988; Andrews et al. 1998; Rodrigue and Burger 2004). Soil depth positively influences mine soil productivity through increased rooting depth and greater water holding capacity (Torbert et al. 1994; Andrews et al. 1998). The soil placement depth required for a less productive forested plant community might not be as thick as that needed for a commercial forest. For increased species diversity, optimal placement depths are variable from thin to thick (DePuit 1984). The application of thin soil layers over substrates that have adverse characteristics (such as salinity and/or sodicity) requires further research. Initial growth might appear successful; but over time the vigour of the vegetation cover may decrease as salts ingress into the overlying soil.

Management Implications:

Planning for reclamation material allocation based on coversoil depth is linked to the target ecosite.

Adaptive Management:

Specific reclamation objectives may suggest deviation from current approval conditions; for instance, re-establishment of jack pine-lichen ecosystems might require use of very thin surface soil layers on suitable subsoil, overburden or tailings sand substrates. It is recognized that some risk would be entailed in such treatments, but operators are encouraged to explore alternative strategies to achieve particular explicit reclamation goals. However, operators are also advised that such exploration should occur on an experimental, as opposed to operational, basis, until novel soil placement techniques can be proven successful.

Knowledge Gaps:

The link between predicted SMR and SNR on reclaimed landscapes and development of a target ecosite/site type needs to be evaluated and defined. Varying soil-cover design depths within a reclaimed landscape to enhance diversity within the AOSR should be evaluated.

SOIL QUALITY DEGRADATION

BMP 22 Preserve soil quality to meet reclamation objectives.

Rationale

Timber harvest, clear and grub, peatland drainage and soil salvage/placement operations can negatively affect the chemical and physical properties of soil if the environmental conditions and equipment used are unsuitable.

Current Practice/Strategy:

EPEA approvals require operators to minimize soil loss and soil degradation. They also require operators to minimize the loss of plant propagules in upland surface soils. Approvals require the suspension of soil salvage operations when soil quality will be degraded by wet or windy conditions. Most pre-salvage and salvage operations are done in the winter because of improved trafficability. Operators typically salvage mineral soils in the fall and winter months, 1 to 5 years after trees have been harvested. Suitable overburden and subsoil are salvaged year-round.

Peatland salvage areas require site preparation through the addition of padding (mineral material) or by pounding frost into the soil. Salvaging peat alone and peat-mineral mixes is almost exclusively restricted to winter months; however, these soils have been successfully salvaged during non-frozen conditions when padding material is available and salvage is required because of rapid mine development. Methods used to improve accessibility include pounding a frost layer deep into the organic layer by dragging haul truck tires behind dozers and, if necessary, placing padding on top of peat or at the base of the salvage pit. Accessibility of a salvage area can be improved through the use of smaller equipment and construction of temporary roads to provide equipment access under thawed conditions.

The type of equipment used is determined by equipment availability, soil moisture conditions and depth of frost. Upland surface soil is typically pushed into windrows using dozers. Suitable overburden is salvaged using excavators. Subsoil, organic soil and peat-mineral mix are usually salvaged using excavators; however, may be windrowed with dozers. Some operators have salvaged upland surface soils and subsoil with scrapers. More detailed information about equipment used for salvage operations can be found in the *Comprehensive*

Report on Operational Reclamation Techniques in the Mineable Oil Sands Region (Macyk and Drozdowski 2008).

State of Knowledge:

Environmental Conditions: Weather conditions and pre-salvage operations (e.g., timber harvest, clear and grub operations and drainage) can change the moisture content of the soil, depth of frost and depth of snow on the surface. Removing the forest canopy cover has a significant effect on the hydrological cycle and physical soil properties (Fisher and Binkley 2000). Clear cutting reduces the water use by trees, but also causes greater snow accumulation on the surface. Soil moisture content can increase substantially after trees have been removed and the depth of frost penetration may also increase.

The moisture content of peat during salvage operations influences site access. Moister peat allows freezing to occur, which results in increased site access. If peatlands are drained too much there may not be enough available water to pound in the frost. Suitable overburden is typically used for padding so that the quality of underlying peat or peat-mineral mix is not compromised. When unsuitable overburden is used for padding, the unsuitable overburden degrades the quality of underlying peat. Unsuitable overburden may contain deleterious elements (e.g., salts) and if mixed with peat, would create an unsuitable peat-mineral mix.

Soil salvage and placement under wet conditions can have negative impacts on the physical, chemical and biological properties of soil when handled and stored. Handling wet soil increases the soil's bulk density and structural breakdown. Severe compaction can be difficult to ameliorate and can lead to a reduction in root growth (Bell 2004). Equipment on wet soils also increases rutting and can result in admixing of upland surface soil with subsoil. The quality of upland surface soil is most often reduced when subsoil is admixed, largely because of the reduction in organic matter content.

Salvaging upland surface soil or subsoil with deep frost penetration increases the risk of incorporating deeper, potentially less suitable, mineral material. Upland surface soils, especially fine-textured upland surface soils that are wet during the fall, are likely to freeze during winter months. If the frost prevents dozers from salvaging to the desired depths, not all upland surface soil will be salvaged. Soil salvage during frozen conditions can reduce the amount of compaction to the subsoil layer and will help reduce the degradation of soil structure. Salvaging upland surface soil under dry, windy conditions may result in soil loss due to wind erosion.

Snow mixed in with reclamation material increases the total volume of material handled and results in less accurate soil volume estimates. Although, some snow provides additional moisture when placed on post disturbance landscapes, excessive snow in reclamation materials can saturate the soil after snow-melt, potentially leading to water erosion during high rainfall events in the spring. Salvaging snow with upland surface soil has short-term benefits when the upland surface soil is stockpiled for less than one year, but when the snow melts the stockpiles become increasingly anaerobic (MacKenzie 2011). Too much snow incorporated with any type of stockpiled reclamation material creates unstable stockpile and may cause the material to become wetter over time.

Propagules: The time of year operational activities occur affects the amount of damage to vegetative propagules. For most boreal plant species, root carbohydrates are most abundant in late fall and winter. Salvaging upland surface soils when plants are actively growing in the spring or summer may reduce plant establishment from roots when upland surface soils are directly placed the following winter. Plants capable of reproducing asexually are least likely to be damaged during fall and winter operations because they are dormant and their carbohydrate reserves in the root systems are highest.

Boreal forest seed bank densities are highest in the fall and winter months. Most boreal plants have seeds that ripen in late summer or early fall. Salvaging upland surface soil after seeds have ripened increases the total pool of viable seeds. The timing of upland surface soil salvage operations and its effects on propagules becomes less important if soils are stockpiled.

Equipment: Equipment needs to be capable of controlling and achieving the required salvage and placement depth. Larger dozers, such as Caterpillar D11 (or equivalent), may work well on relatively flat landscapes; however, larger dozers with very wide blades may not be able to control the salvage depth as effectively in hummocky terrain or where upland surface soil depths are variable. Caterpillar D8 to D10 dozers (or equivalent) with wide tracks may be the most versatile dozer sizes for salvaging upland surface soils. Dozers of this size can move large amounts of material in the presence of large roots and stumps while accurately maintaining depth control.

Scrapers are versatile machines for selective removal of soil horizons, but they can cause significant compaction of underlying material (Bell 2004). Some of the advantages of using scrapers include: increased depth control; less frequent passes required to salvage soil in a specific area; and increased cost efficiencies if haul distances are short. However scrapers offer reduced operability in frozen conditions and in rolling, steep terrain. In addition, scrapers require higher quality clear and grub operations prior to soil salvaging (e.g., stump removal, snow removal). Additional site preparation required for clear and grub operations may increase the risk of damaging propagules or increasing the amount of forest floor that gets incorporated with woody debris.

The type of equipment used can influence the degree of compaction. Excavators are better than scrapers or dozers when trying to reduce the handling and compaction of subsoil and suitable overburden. Using both excavators and dozers is preferred to using only dozers or scrapers. Dewatering programs can help reduce the moisture content of soils.

Management Implications:

Because of unpredictable weather and modifications to mine plans, operators may not be able to salvage and place soil under optimal conditions. Peat-mineral mix and peat are typically salvaged under less-than-optimal conditions because they are saturated. Deferring salvage operations until soil conditions are optimal is not recommended if postponement of the salvage operations results in creating less suitable salvage conditions in the future (e.g., wet soil) or creates a risk of not salvaging soils at all. Using overburden that is both physically and chemically suitable for use as padding can be costly if the haul distances from the source are long.

Qualified Environmental Monitors: Alternatively, qualified soil surveyors conduct pre-disturbance soil quality assessments to develop soil salvage plans. During salvage, monitors can steward to these plans to ensure operators are meeting salvage specification requirements. Developing a soil salvage plan prior to salvage requires less soil quality assessments to take place during salvage resulting in greater work efficiency and less confusion, which in turn improves soil quality of salvaged materials. Refer to BMP #1 for more detail regarding soil salvage planning.

Adaptive Management:

Timing of Operations: Soil quality is best preserved if pre-salvage, salvage and placement operations are done during fall and winter months. Operators should harvest timber in winter, salvage soil the following fall and haul to stockpiles or placement areas in the winter. Salvaging soils during dormant periods of the year will also help preserve the viability of propagules.

Environmental Conditions: Equipment operation on dry or frozen soil is preferred to wet soils because compaction is reduced and fewer ruts occur. However, delaying upland surface soil salvage operations to a point where the frost penetrates too deep can cause serious admixing during salvage and possibly prevent salvage of all upland surface soil. When frost is deeply penetrated within the soil profile, ripping the upland surface soil layer prior to salvaging may help reduce the risk of admixing.

Accessing a site with finer-textured PGM under frozen conditions reduces traffic-related compaction of the subsoil and suitable overburden layers. Sites with coarse-textured PGM are not as susceptible to traffic-related compaction compared to finer-textured PGM; therefore, B horizon soil or suitable overburden with coarse PGM may be salvaged during non-frozen conditions.

Incorporating excessive amounts of snow when salvaging upland surface soil should be avoided. There is no definitive limit of snow that can be incorporated into upland surface soil; however, operational experience suggests a 30 cm maximum depth. Snow clearing activities should not incorporate any forest floor with the snow that gets cleared off the site.

Unsuitable overburden should not be used as padding over suitable reclamation materials or peat. When salvage operations advance out from the salvage area, suitable overburden used for padding can then be re-salvaged along with the underlying peat. Suitable reclamation material such as peat-mineral mix, upland surface soil and subsoil should not be used as padding material on unsuitable overburden or used for constructing temporary or permanent access roads.

Repeated Handling: Operators should minimize repeated handling of soils. Increased handling of soils degrades soil structure and increases the amount of organic carbon lost. Soils that are fine-textured, such as subsoil from B horizons, are more prone to soil structure degradation than coarse-textured soils.

Equipment Selection: Operators should use equipment that minimizes soil quality degradation and the loss of viable propagules. Select the appropriate sized equipment to maximize the push distance and reduce the number of pushes required to salvage upland surface soil at a particular depth. More frequent paths along the same salvage area result in increased damage to roots and seeds and degradation of the original soil structure. Qualified planners should be consulted to select appropriate equipment to match site conditions.

Visibility: Upland surface soils should be salvaged in daylight as this increases the success of maintaining the desired salvage depth. If time constraints arise and salvage operations must occur at night, survey stakes and/or supplemental lighting should be used to assist in maintaining the desired salvage depth.

Qualified Environmental Monitors: Having qualified soil specialists on-site can help prevent a loss in soil quality as environmental and soil conditions change throughout the salvage operations. Monitors must be competent in understanding soil surveys to ensure that the data are verified in the field. Unexpected differences between the soil survey and conditions in the field must be identified so that upland surface soil is salvaged properly. In addition, monitors must be able to characterize soil properties to make decisions regarding salvage depth, segregating soil types, salvage timing and to ensure they are able to shut down soil salvage operations under conditions that might degrade soil quality.

Knowledge Gaps:

Limitations to site access may result in a failure to salvage reclamation materials of higher quality within the surrounding peatlands. Methods that improve access to better quality reclamation materials need to be further assessed. In addition, the effects of dewatering on the quality of organic matter in fens and bogs are unknown.

POST-PLACEMENT SITE PREPARATION

BMP 23 Leave coversoil rough on the surface.

Rationale
Rough surfaces (10 to 50 cm microtopographic relief) create:

- Microsites that enhance native seed/spore catch and increase germination and emergence of in situ propagules and create localized changes in soil and moisture regime;
- Habitat for small animals and soil fauna; and
- Erosion control.

Current Practice/Strategy:

Initial placement of peat-mineral mix often results in large clumps of peat, mineral soil or a mixture of peat and mineral soil (e.g., >1.0 m) left on the surface, leaving exposed suitable overburden adjacent to the large clumps. Crawler tractors are used to re-spread the large clumps of peat. Large frozen clumps of peat are re-spread between early spring and early summer. Upland surface soil does not typically receive additional site preparation as it spreads well during placement if it does not include high amounts of WD.

Various preparation methods have been used to improve the mixing of peat and mineral soil and to reduce erosion. Some of these methods include: rotovating peat and mineral soil, ridging, plowing, furrowing, harrowing and imprinting the coversoil (Macyk and Drozdowski 2008). Most of these practices have been discontinued because peat salvaged with mineral soil is adequately mixed and less mixing establishes more diverse plant communities. Ridging, furrowing and imprinting were historically used to control erosion, but since the introduction of annual cover crops these practices have also been discontinued.

The amount of traffic on upland surface soil should be minimized to prevent degradation of soil structure and loss of viable propagules. Upland surface soils should be redistributed using one pass with a crawler tractor blade. Use of larger crawler tractors (e.g., D8 to D10 Caterpillar) helps minimize the amount upland surface soils are moved around, compared to smaller crawler tractors (e.g., D6 Caterpillar). Transitional soils are treated in the same way as upland surface soil.

State of Knowledge:

A rough surface is desirable for plant establishment and promotes the development of more diverse plant communities. Incorporating woody debris during salvage operations helps promote the creation of rough surfaces, providing microsites for seeds, plants, soil organisms and small animals. Smoothing out peat-mineral mix coversoil is a common practice to help mix peat and mineral soil, to break up large clumps of frozen peat-mineral mix and to create a seedbed for the cover crop that is intended to control erosion in the initial year(s) of reclamation. Peat-mineral mixes are mixed well during the salvage and storage operations; this eliminates the need to remix soils after placement.

Frozen clumps of peat-mineral mix are spread during spring and early summer. At this time most plants are emerging from vegetative propagules and some plants from seed. There is a high mortality rate of plants establishing from in situ propagules throughout this process. Peat-mineral mixes experience the same benefits of a rough surface as upland surface soils. Smoothing out the surface of peat-mineral mix should be avoided; although, some areas that have large clumps of peat may need to be broken and spread out.

Management Implications:

It is more difficult to determine average placement depths on rough surfaces. It is also harder to use agricultural equipment for post-placement activities (e.g., seed cover crop for erosion control in the early year(s) of reclamation).

Adaptive Management:

Blading of the surface and reducing traffic can help keep the surface rough. Traffic and other activities on the surface of coversoils during the active growing season should be minimized. If surfaces are smoothed out because additional site preparation is required (e.g., adding additional coversoils to meet minimum depth requirements) then scarification equipment can be used to roughen the surface. Obtaining average placement depths on rough surfaces can be difficult when using traditional verification methods (e.g., pits or auger) and when using low sample densities. An alternative to increased sample densities is to record volumes of coversoil placed. If the volume of coversoil has been placed in quantities to meet reclamation objectives then placement operations should meet the environmental outcomes. The use of pre- and post-disturbance LIDAR scans may also provide an opportunity for assessing volume of soil placed (see BMP #1).

Image 18. Placement of peat-mineral mix with a rough surface early after the first growing season.

The addition of woody debris keeps the surface rough. Few best management practices exist for applying woody debris because of the knowledge gaps associated with its application. Application rates of woody debris should be based on reclamation objectives. It should be placed on areas where the establishment of biodiversity and erosion control are the primary objectives. Best management practices for woody debris should be updated when more information is available (see BMP #3).

Knowledge Gaps:

The optimal roughness required for various types of coversoil likely requires refinement. It may be that different degrees of surface roughness are required for different coversoils, plant communities, slopes and aspect.

POST-PLACEMENT SITE PREPARATION

BMP 24 Use fertilizer applications specific to reclamation objectives for a site.

Rationale

Inappropriate use of fertilizer can be detrimental to desirable plant species; therefore, fertilizer applications should be site specific and based on soil and/or plant tissue analysis. Applying fertilizer before, or recently after, soil placement or planting of woody species often promotes the establishment weeds and a plant community dominated by herbaceous plants. Weeds and herbaceous plants can outcompete planted trees and shrubs and prevent ingress of desired locally common boreal species.

Current Practice/Strategy:

Fertilizer amendments have been an integral part of oil sands reclamation because coversoils may not contain the concentrations of nutrients needed to establish desired plant community types. Where possible, fertilizer is incorporated into the surface soil using ground equipment. Ground application may give more complete coverage of areas compared to aerial application. Aerial application is useful for fertilizing areas that are not accessible by ground equipment (e.g., steep slopes, wet areas or rough terrain).

The types of fertilizer used, fertilization rates and methods of incorporation have changed over time based on soil nutrient analysis, competition from herbaceous species, and tree and shrub growth. Fertilizer application on reclaimed landscapes is completed in stages. Fertilizer is initially applied at a heavy rate (starter application), and some operators apply annual applications (maintenance applications). Fertilizer may be applied every three to five years for a company-specific period of time. Less fertilizer is used in the annual applications. The starter application of fertilizer is critical to maintain the necessary nutrient pool in reclamation cover soils (Techman Engineers Ltd. 1983). Specific details about current fertilizer application rates and methods are presented in the *Comprehensive Report on Operational Reclamation Techniques in the Mineable Oil Sands Region* (Macyk and Drozdowski 2008). Inoculation techniques (e.g., fertilizer, mycorrhizae) of tree seedlings are being explored.

State of Knowledge:

Forest fertilization carried out at different times of the year has shown different uptake and growth responses. The amount of soil that a newly planted tree can exploit is inadequate to supply its requirements for water and nutrients, because the root system is initially small and confined to the planting hole (van den Driessche et al. 2003). van den Driessche et al. (2003) determined that fertilizing aspen seedlings under climatic conditions near Drayton Valley (without irrigation) did not increase growth, but reduced the survival of aspen seedlings. In early spring, soils are cold and the cold soil temperatures inhibit nutrient movement and may limit uptake capabilities (Amponsah et al. 2004). Amponsah et al. (2004) determined summer and fall applications of nitrogen fertilizer (^{15}N) resulted in greater ^{15}N uptake by lodgepole pine seedlings compared to spring application.

Fertilization often increases the growth and survival of tree and shrub species; however, application of fertilizer also increases the growth of undesired, competitive herbaceous species causing increased mortality rates of shrubs and trees. Applying large amounts of fertilizer is unnecessary when the root systems of the plants are not sufficiently developed to handle the increased nutrient levels or if the moisture is insufficient to put the chemicals into solution. Tree seedlings typically do not require fertilization immediately after out planting and most fertilizer is taken up by surrounding herbaceous plants (Staples et al. 1999). Continuous high application rates of fertilizers that do not get incorporated into the soil tend to encourage the growth of competitive herbaceous species.

Management Implications:

Fertilizer practices need to support reclamation objectives. There are additional costs associated with multiple fertilizer applications and possible detrimental effects on the sustainability of forest growth in fertilized soils.

Adaptive Management:

To encourage native vegetation establishment, application of fertilizer is not recommended unless soil and plant tissue analysis indicates the application of fertilizer supports vegetation establishment as per reclamation objectives. Delaying fertilization until tree and shrub seedlings have established can help reduce mortality from herbaceous plant competition.

It is considered best practice to avoid fertilizing upland surface soils assuming nutrient concentrations are present in sufficient amounts to meet reclamation objectives. Upland surface soils have an abundant supply of nutrients to support shrub and tree growth. Research is underway to assess the impact of fertilization on plant community establishment on upland surface soils. As more upland surface soils are used in reclamation, soil and plant nutrient analysis can be used to verify whether or not fertilization is required.

If fertilization is required, the frequency, rate and type of fertilizer should be based on a series of ongoing soil and plant tissue analyses that are designed to monitor the nutrient status of the soil and plants, the pH and moisture availability of the soil, as well as the growth characteristics of the plants. This information needs to be documented.

Cover crops may need fertilization. The use of cover crops can improve tree seedling growth. Application of fertilizers for purposes of establishing a cover crop should be determined from soil nutrient analysis and reclamation objectives.

Knowledge Gaps:

There are several knowledge gaps related to fertilizer use, and they are similar to the gaps that existed 30 years ago. Although peat-mineral mixes and peat-alone are believed to need fertilization, it is not known when the initial application of fertilizer should occur. Early application of fertilizers may condition shrub and tree seedlings so that they require repeated fertilization. This is not a sustainable practice. Planting tree and shrub seedlings that have not been conditioned with nutrient additions in nurseries could help reduce the amount of fertilizer needed to establish these plants. Although research using different types of fertilizers at different application rates has been completed, this information is difficult to incorporate because of the substantially different soil handling practices used today.

Further research is required to investigate the inoculation of trees to optimize and focus the fertilizer application rate to the intended vegetation species, rather than widespread indiscriminate fertilizer applications to the soil via techniques such as broadcast fertilization.

As new technology and fertilizer products are introduced, additional gaps are created. As a starting point, operators are encouraged to leave some areas reclaimed with unfertilized peat-mineral mix adjacent to areas that have been fertilized. Frequent monitoring of soil and plant tissue nutrient concentrations and plant growth on fertilized and unfertilized areas can help reduce the knowledge gaps that presently exist.

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APPENDIX A: Salvage of Reclamation Material with Indigenous Hydrocarbons

Salvage of Reclamation Material with Indigenous Hydrocarbons

Submitted by the Hydrocarbon Task Group

of the Terrestrial Subgroup

1. Introduction

In 2005, the Soil and Vegetation Sub-Group (SVSG) [now the Terrestrial Sub-Group (TSG)] of the Reclamation Working Group of the Cumulative Environmental Management Association (CEMA) identified the need to assess the consequence of naturally occurring petroleum hydrocarbons (hereafter referred to as 'indigenous PHC') in reclamation materials. During discussion of this subject in 2006, the Government of Alberta indicated that any assessment criteria pertaining to indigenous PHC needed to align with the current provincial regulatory framework, as opposed to standing alone. In 2007, this knowledge gap was recognized in Industrial Approvals for Oil Sands mines (under the *Environmental Protection and Enhancement Act*) with the requirement for 'development of a risk-based approach for defining acceptable concentrations of naturally occurring hydrocarbons in reconstructed soils.' Several studies (listed as references) have been carried out for TSG to better understand the distribution of indigenous PHC in regional soils and their toxicological effects. Results of these studies were reported back to TSG. In 2009, the Hydrocarbon Task Group was formed with the objective of reviewing and interpreting this work to provide clear direction on soil salvage and placement operations.

2. Background and Problem Definition

Within this note the term 'soil' is used as defined in the Canadian System of Soil Classification. Indigenous PHC are present in some soils and parent geologic materials in the Oil Sands region. Where present they may influence soil quality and function, and thus, vegetation community establishment. Based on the limited information available, it is not possible to provide a comprehensive description of the effects of indigenous PHC on soils and vegetation in their natural state, and be certain that the effects of indigenous PHC in the natural setting will translate to the reclaimed environment.

Redistribution of indigenous PHC during salvage, stockpiling and placement of reclamation materials may increase exposure to receptors. Hydrocarbons in the reclaimed environment may inhibit plant establishment and growth, and interfere with soil biota that mediate decomposition, nutrient release and in some instances (e.g., mycorrhizae) nutrient uptake.

Because indigenous PHC may be present in much of the landscape, exclusion of upland soil from salvage due to the presence of indigenous PHC would significantly reduce the volume available for reclamation. For example, at Shell Albian Sands indigenous PHC were observed within 3 m of the surface at 299 of 453 locations (66%) (Paragon Soil and Environmental Consulting Inc. 2006). Any reduction in the volume of upland soil salvaged will only increase the already large extent of peat-mineral mix planned for the post-disturbance landscape. In such cases, salvage quality can only be defined in an optimization scheme that explicitly considers both quality and volume.

The most recent changes to Industrial Approvals for Oil Sands mines require salvage of all upland surface soil and subsoil, along with an overstrip of transitional (Gleysolic) soils. This low-risk strategy targets the native soils that sustained vegetation on the pre-disturbance landscape.

Definition of acceptable concentrations of indigenous PHC in reconstructed soils is problematic. The document that has been used to assess the reclamation suitability of salvaged soils [*Soil Quality Criteria Relative to Disturbance and Reclamation* (revised March 1987, Alberta Agriculture)] does not include hydrocarbon content, and the criteria provided in *Alberta Tier 1 Soil and Groundwater Remediation Guidelines* (2009, Alberta Environment) are intended for substance release and hence not directly applicable. Furthermore, concentrations of indigenous PHC in native soils have been shown to exceed Alberta Tier 1 soil remediation guidelines.

Currently some Oil Sands mines employ a precautionary approach that defines a ‘cut off’ depth for soils containing indigenous PHC. In one application, hydrocarbon concentrations >1% are used to identify unsuitable reclamation material and delineate the depth of soil salvage. A second application relies on visual assessment where if >25% of the surface area of the exposed profile is impacted by indigenous PHC, the reclamation material is judged to be unsuitable.

3. Rationale

Our review of information listed as references identified key findings and their implications for operations. This briefing note does not provide a summary of specific studies.

At the outset we recognized that the concentration of indigenous PHC does not provide an effective basis for assessment at this time, for several reasons. Firstly, when concentrations were reported in soil surveys it was unclear how to interpret them in respect of relevant exposure pathways and receptors. Likewise, while microcosm studies provided important preliminary information on toxicology, they did not include all relevant receptors at all relevant scales. Secondly, as indicated previously, *Alberta Tier 1 Soil and Groundwater Remediation Guidelines* is intended for substance release and hence not directly applicable. Moreover, the guidelines set out apply to mineral soils as opposed to organic soils. At the same time, the guidelines cannot be completely ignored. They provide objective criteria for interpretation of results of toxicological trials and some of the principles underlying their derivation are relevant and informative. For example, in the case of a peat-mineral mix: '… groundwater remediation guidelines may be used for organic contaminants in organic soil' (Alberta Environment 2009, p. 32). This statement directed our attention to whether hydrocarbons were leached from tar balls in laboratory studies. A microcosm study by Visser (2008a) indicated no leaching of hydrocarbons from tar balls, despite large concentrations of hydrocarbons in the tar balls (47,000 to 83,000 mg kg-1) and regular watering. Given the large molecular size and complexity of F3 (>C16-C34) and F4 (>C34) hydrocarbons, leaching from tar balls would be expected to be negligible.

In 2006, SVSG recognized the need to better define the extent of indigenous PHC in regional soils. Information was compiled from sources reporting observations and/or characterization of indigenous PHC (environmental impact assessments, soil salvage plans, etc.). A supplemental field survey was also conducted in pre-selected areas where indigenous PHC were expected to be present by Paragon Soil and Environmental Consulting Inc. (2006). The survey focused predominantly on upland landscape positions. The report concluded that approximately half of the more than 1000 inspection sites contained indigenous PHC as tar balls or bitumen/tar sand layers in the uppermost 3 m. The hydrocarbon content ranged from high (>25% of the soil layer stained with hydrocarbons) to trace amounts (<5% of the soil layer stained with hydrocarbons), with F3 and F4 hydrocarbons predominant. The survey also determined that specific vegetation communities (ecosites) appear to develop in these areas dependent upon the proportion of the indigenous PHC in the soil profile.

The occurrence of indigenous PHC in regional soils that support functioning ecosystems defines background soil quality at some locations on the pre-disturbance landscape and cannot be ignored as such. ‘In some situations, the background concentration of some substances can be a significant proportion of, or even exceed, the Tier 1 guidelines. In cases where the natural background is demonstrated to be greater than Tier 1 guidelines, the remediation level shall be to natural background or to guidelines developed using Tier 2 procedures’ (Alberta Environment 2009, p. 8). Application of this principle is constrained by the fact that indigenous PHC occur in some but not all regional soils, and disturbance of reclamation material in salvage, stockpiling and placement may redistribute indigenous PHC in a manner that aggravates their experience by some receptors. For example, tar balls may break open and expose a relatively less weathered surface. Furthermore, the argument for an elevated background concentration would not apply to situations where indigenous PHC are intentionally introduced into reclamation material that was originally free of it. Rather, ‘soil or groundwater with naturally elevated substance concentrations may become a source of contamination if it is redistributed and causes the receiving soil or water to exceed Tier 1 or 2 remediation guidelines’ (Alberta Environment 2009, p. 6). Finally, where tar balls occur on the landscape, it may be unreasonable to discriminate between the presence of indigenous PHC in soil and the underlying parent geologic material from which it has developed.

Tar balls are composed primarily of heavier, complex hydrocarbon fractions (F3 and F4), with a small amount of F2 (>C10-C16) hydrocarbons. Their content of benzene, toluene, ethylbenzene and xylenes (BTEX), and F1 (C6-C10) hydrocarbons is negligible. The heavier fractions tend to be less bioavailable and hence more restricted in terms of exposure pathways but also less amenable to degradation. In the course of a microcosm study (Visser 2008a), tar balls lost approximately 7.5% of their hydrocarbon content through degradation. Tar balls did not impede growth of barley (*Hordeum vulgare* L.), aspen poplar (*Populus tremuloides* Michx.) and white spruce (*Picea glauca* (Moench) Voss) in microcosms. There may have been less root growth of jack pine (*Pinus banksiana* Lamb.) in the presence of tar balls. Tar balls did not impede colonization of roots of the three tree species by ectomycorrhizal fungi, although some species of ectomycorrhizal fungi may be sensitive. In contrast to the plant species used in reclamation, tar balls did impede growth of juvenile earthworms (red wiggler; *Eisenia andrei* Bouché) but not the survival and growth of adults. It is not clear how directly applicable the impact of tar balls on earthworms (intended as surrogates of the soil macrofauna) is to biota of regional soils. Results of these toxicological trials with selected receptors were consistent with expectations based on the chemistry of tar balls and the predominance of heavier fractions that are less bioavailable.

The lean oil sand (LOS) study (Visser 2008b) represented an inadvertent introduction of objectionable material into the soil profile of the reclaimed landscape. Current Industrial Approvals for Oil Sands mines require that ‘impervious conditions such as lean oil sand or rock’ and ‘reject from the oil sands conditioning and transport system’ be capped with ‘an average minimum of 1.0 m of tailings sand or overburden prior to placement of reclamation material.’ As indicated above, such material may become a source for substance release if introduced into the soil profile. The LOS study may also provide inference about the consequence of exposure of relatively unweathered components of indigenous PHC when they are disturbed in the salvage operation and redistributed in reconstructed soils.

Lean oil sand contained no detectable BTEX, very little F1 hydrocarbons (approximately 0.15%) and some F2 hydrocarbons (8.6%). Most of the total hydrocarbon content was accounted for by F3 (38%) and F4 (53.8%) hydrocarbons. Incubation and weathering of LOS for 130 days resulted in removal of hydrocarbons through volatilization, biodegradation or sorption, with the lighter fractions most affected. On average 100%, 75%, 35% and 0.7% of the F1, F2, F3 and F4 fractions, respectively, was lost, representing 25% of the total hydrocarbon content. It was surprising that the removal of hydrocarbons differed little between the two matrices – silica sand alone or amended with peat. The temporal pattern of hydrocarbon loss indicated that weathering cannot be relied on to reduce concentrations of indigenous PHC to values less than applicable Alberta Tier 1 soil remediation guidelines. At the same time, weathering would be expected to reduce (but not eliminate) exposure to receptors. Weathered hydrocarbons were less toxic to specific receptors (barley, aspen poplar, white spruce, jack pine and earthworms). Moreover, receptors appeared to be more tolerant to weathered LOS in presence of peat. Visser (2008b) attempted to interpret the results against Alberta Tier 1 soil remediation guidelines and infer critical hydrocarbon concentrations, which would not constrain plant productivity. However, at this time it is difficult to extrapolate from a microcosm study in which receptors experienced a definite concentration of hydrocarbons to the field where concentration is a more ambiguous description of what receptors experience. Earthworms were more sensitive to LOS than the plants. As for tar balls, the relevance of results with earthworms for regional soils is unclear. Most of the soil biota involved in decomposition and nutrient release would occur in surface litter, the A horizon or the rhizosphere/detritosphere. The total percentage abundance of ectomycorrhizal fungi decreased with increasing concentrations of unweathered LOS. It is worth noting that results of the LOS study support in principle the requirement in Industrial Approvals for Oil Sands mines for capping LOS.

4. Recommendations

When present as tar balls, indigenous PHC do not present a severe risk to ecological receptors. Hence the presence of indigenous PHC in this form does not warrant exclusion from the current requirements in Industrial Approvals for Oil Sands mines for salvage of upland soil. This general recommendation may be conditioned by other concerns and amended on a case-by-case basis. For example, the physical structure (e.g., an indurated layer) and extent of indigenous PHC in upland soil at a specific location may be such that the operator chooses to exclude it from salvage. Our judgment was based on only two toxicological studies and hence may change as more information becomes available. Therefore, we recommend that the relative amount of upland soil containing indigenous PHC be tracked in the Soil Salvage Plan and Annual Conservation and Reclamation Report.

Further research should be undertaken to determine if indigenous PHC in upland soils differ from those in the underlying parent geologic material. This situation is distinct from that where LOS from well below the soil profile is redistributed into the surface cap of reclamation material, which may be viewed as substance release. Our recommendations were focused on soil salvage. Further research should be undertaken to determine the minimum depth requirement of reclamation materials on overburden containing LOS. Moreover, the potential effects of indigenous PHC on other soil properties (e.g., available water-holding capacity), has not been evaluated and may require future attention in guideline documents such as the *Land Capability Classification System for Forest Ecosystems in the Athabasca Oil Sands Region*. Field-scale trials and retrospective studies will provide further information that may better inform placement of reclamation material containing indigenous PHC.

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