REMOVING THE WELLSITE FOOTPRINT:

Recommended Practices for Construction and Reclamation of Wellsites on Upland Forests in Boreal Alberta

Terry Osko and Maggie Glasgow

Revised 2010

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Executive Summary

Wellsite reclamation criteria in Alberta have historically been based on a paradigm of returning land to equivalent land capability. Unfortunately, this paradigm has treated all landscapes as equivalent and therefore has not addressed differences in ecological function, land use, or economic opportunities associated with unique land types (forests, peatlands, grasslands, agricultural land). As a result, previous wellsite reclamation criteria have been successful in protecting reclaimed wellsites on forested land from soil loss by erosion, but have been unsuccessful in restoring ecological function or their natural ability to grow a forest. Wellsites drilled and abandoned on forested land in Alberta during the 1960’s through much of the 1990’s have generally been very slow to recover to natural forest. Many sites have remained relatively barren of trees, while trees on sites that are more densely treed are much smaller than would be expected from the age of the sites. Our goal for this project was to contribute to best practices for wellsite construction and reclamation on forested lands within the Green Area of northeastern Alberta that will enable appropriate revegetation and accelerate recovery of ecological processes after disturbance. The desired outcome of which are functioning forests that contribute to both the ecological and economic health of Alberta. We investigated past, present, and potential practices to discover opportunities to enhance reclamation success on boreal wellsite disturbances in terms of ecological recovery, addressing three main questions: What factors or combination of factors lead to impaired site productivity or ecological impairment? Can these factors be mitigated during the construction phase? If not during construction, can these factors be mitigated during reclamation? We focused primarily on two types of construction, winter-constructed upland wellsites and permanent clay pads built on lowlands from borrowed clay fill, as well as the borrow areas associated with clay pads. Our recommendations result from empirical observations of various wellsites including historical oil & gas wellsites constructed from the 1960’s to 1990’s, previously constructed *in situ* Oil Sands Exploration (OSE) wells (winter 2002/03), new winter-constructed sites selected for study treatment, observation well pads constructed from borrowed clay fill, and borrow pits. Additional recommendations have been made based on general observations of practices and processes involved in completing winter OSE well drilling programs, as well as interviews with drilling and other relevant contractors.

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Disclaimer

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1.0 Introduction

1.1 History of Wellsite Reclamation on Forested Land

Defined criteria for wellsite reclamation on forested land in the Green Area of Alberta have historically been sparse compared to White Area criteria. For any wellsite, the objective of reclamation is the return of "equivalent land capability" to the site (Alberta Environment, 2000). However, the idea of land capability has focused primarily around the ability of land to produce agricultural crops, with little recognition of site ecology or economic value of non-agricultural lands. Before 1983, there was no requirement for topsoil conservation on any wellsite whether or not it was located on agricultural land. Since then, the wellsite reclamation criteria have been updated and improved several times with the latest applicable revision in 1995. Despite progressive improvements to the wellsite reclamation criteria, the focus of criteria presently in use (1995) remained on improving practices on agricultural lands, while practices on forested and other non-agricultural lands were largely ignored (Table 1.1).

Recently, greater attention has been given to improving practices on forested lands. However, a major obstacle in developing effective criteria for forested lands has been the equivalent land capability paradigm. Rather than developing practices based on understanding and maintaining the ecological functions of forested lands, practices applicable on agricultural lands (predominantly former grasslands) were imported into the forest. Alberta Sustainable Resource Development issued a new guide to reclamation criteria on forested lands in 2007 (ASRD 2007). The new guide attempts to shift the focus from agricultural/silvicultural production to ecological function. This is accomplished by better defining what some of the acceptable outcomes of forested land reclamation are, such as increased surface roughness, use of woody debris for soil stabilization, diversity of re-colonizing plant communities, reduced soil restrictions to natural drainage and root development, and so on. The new guide encourages re-thinking what successful reclamation on forested land entails by providing an alternative vision of the reclamation product. In addition to the new guide, revision of criteria for all land types (cultivated, native grassland, forested, and peatland) is to be released in 2010. In any case, neither the 2007 guide nor the 2010 revision directly address the use of specific practices in achieving desired outcomes. As such, it is difficult to tell as yet how the criteria will influence practices and whether longer term desired outcomes of forest ecosystem function will be achieved.

Table 1.1 Reclamation Criteria for forested lands in the White and Green Areas (Adapted from AB Env 2000)

<table>
<tr><th></th><th colspan="2">CRITERIA FOR VARIOUS LAND USE CATEGORIES</th></tr>
<tr><th>Assessment Factor</th><th>White Area</th><th>Green Area</th></tr>
<tr><td colspan="3">1. Landscape</td></tr>
<tr><td>Drainage</td><td colspan="2">• Consistent with original pattern, direction and capacity</td></tr>
<tr><td>Erosion</td><td colspan="2">• No more gullies or blow-outs than on adjacent land</td></tr>
<tr><td>Contours</td><td colspan="2">• Must conform to adjacent contours</td></tr>
<tr><td>Stability</td><td colspan="2">• No visible slope movement, slumping, subsidence or tension cracks</td></tr>
<tr><td>Gravel & Rocks</td><td>• No piles, windrows or concentrations
• No more than an increase of 20% surface cover of gravel & rock</td><td>• No piles, windrows or concentrations
• Meet requirements of approved surface disposition on Public Land</td></tr>
<tr><td>Debris</td><td>• No industrial or domestic debris allowed
• Remove large roots and slash with brush rake
• Remaining slash and roots must not interfere with adjacent or normal land use</td><td>• No industrial or domestic debris allowed
• No large roots and slash, removable by brush rake, allowed unless otherwise specified in approved surface disposition on Public Land</td></tr>
<tr><td>Vegetation</td><td colspan="2">• Should be healthy and suitable for site</td></tr>
<tr><td>Bare Areas</td><td colspan="2">• No increase in number or size compared to original or control</td></tr>
<tr><td colspan="3">2. Surface Soil Replacement Depth</td></tr>
<tr><td>Required</td><td>• 80% of control depth post-1994
60% of control pre-1994</td><td rowspan="3">• Replace all available surface soil as evenly as possible</td></tr>
<tr><td>Minimum</td><td>• 80% of required depth</td></tr>
<tr><td>Average on Site</td><td>• Equal to or greater than required depth</td></tr>
<tr><td colspan="3">3. Surface Soil Quality</td></tr>
<tr><td>Texture
Aggregate Size
Aggregate Strength</td><td>• Remain in same class as control</td><td rowspan="3">• No Criteria</td></tr>
<tr><td>Gravel & Rocks</td><td>• No piles, windrows or concentrations
• No more than an increase of 20% surface cover of gravel & rock</td></tr>
<tr><td>Organic Matter Loss
(estimated admixing)</td><td>• Non-topsoil materials in replaced surface soil should not exceed: 30% Post-1994, 40% 1983-1994, N/A Pre-1983
(Target Only - Not Criteria)</td></tr>
<tr><td colspan="3">4. Process Restrictions</td></tr>
<tr><td>Water Permeability
Vertical Rooting
Soil Aeration</td><td>• Identify soil to 50 cm as restrictive or non-restrictive with respect to the three processes</td><td>• No Criteria</td></tr>
<tr><td colspan="3">5. Vegetation</td></tr>
<tr><td>Species Composition</td><td colspan="2">• Species Composition Type and mix of species should be compatible with original or control species, or meet reasonable land management objectives</td></tr>
<tr><td>Density
Height</td><td>• Equal to or greater than 80% of control</td><td>• No Criteria</td></tr>
<tr><td>Cover</td><td>• Equal to or greater than 80% of control</td><td>• Equal to or greater than 80% cover of plants, litter, and woody debris</td></tr>
<tr><td>Health</td><td>• Plants should be healthy</td><td>• No Criteria</td></tr>
</table>

1.2 Historic Forest Wellsite Reclamation Success

Reclamation success depends very much on how success is defined. As noted above, Alberta Environment's stated objective for land reclamation in the past has been to return the land to equivalent land capability. In the most basic terms, this has meant minimizing any diminishment in a site's ability to support vegetation (e.g. no soil losses to erosion, no major losses to soil fertility, etc.). From this simple perspective, past wellsite reclamation practices on boreal forest sites have been successful. However, this apparent success has not reflected what contribution the site makes to the ecological function of its surroundings or the potential economic effects of deviations from "normally expected" ecological functions. Poor regrowth of forest vegetation on boreal forest wellsites suggests that reclamation practices of the past have not been as successful on the basis of returning expected ecological functions to wellsite disturbances in a reasonable period of time (Osko and MacFarlane 2001). In fact, vegetation succession on past wellsite disturbances appears to stagnate, meaning that natural regrowth of typically expected forest vegetation is so slow that it appears not to be occurring.

Osko and MacFarlane (2001) measured tree densities (stems/ha), heights, and diameters on wellsites within aspen-dominated stands that ranged from about 2 to 40 years from the time of well abandonment. The wells were all non-producers and were abandoned within 3 weeks of drilling. Wellsite measurements were compared to similar measurements on correspondingly aged (2, 14, and 28 years) timber harvested or forest fire-affected areas within aspen-dominated stands. There averaged about 20,000 and 100,000 stems/ha on the youngest cuts and burns, respectively. These declined through natural self-thinning to about 3500 and 6500 stems/ha on the 28 year-old cutblocks and burns, respectively (Table 1.2). By contrast, mean stem densities on wellsites increased from about 3600 stems/ha on the youngest sites to 8600 stems/ha on the oldest sites. While older wellsite disturbances were abundantly stocked in comparison to similarly aged cuts and burns, the size of trees was surprisingly small. Mean stem diameter at breast height (dbh) was 2.83 cm on the oldest classes of wellsites and the diameter of most stems on the oldest wellsites was 1 cm (Table 1.2). On the other hand, mean diameters on fire and harvest sites were greater than 6 cm on the oldest sites and most stems on 28 year-old fire and harvest sites were 5 cm in diameter. Stem heights increased with age of site on all disturbances, but only 4% of stems on wellsites were taller than 5 m on the oldest sites Table 1.2. In fact, almost 93% of stems on the oldest wellsites were less than 3 m tall. Meanwhile, more than 80% of stems on 28 year-old burns and cutblocks were greater than 5 m tall. Furthermore, despite seeming to be abundantly stocked numerically, the distribution of trees on wellsites was not uniform. Trees were extremely densely spaced along the edges of leases, while much of the interior of wellsites remained treeless.

Table 1.2. Comparison of tree characteristics on various disturbance types after at least 20 years (adapted from Osko and MacFarlane 2001).

	Stems/ha	Mean Stem Diameter (cm)	Most Frequent Stem Diameter	Proportion of Stems > 5m Tall
Natural Fire[1]	6500	6.14	5	82
Harvest Cutblock[1]	3500	6.47	5	83
Wellsite[2]	8600	2.83	1	4

[1]Fire and harvest data from Alberta Research Council (Crites unpubl.); n = 3 for both Fire and Harvest at 28 years post-disturbance.
[2]Disturbance age class for wellsites was >20 years; n = 23.

Natural reforestation on wellsites differed considerably from regrowth on cutblocks and burns (Fig. 1.1). The probable cause is that wellsite disturbances differ from fire and timber harvest and that the conditions left for reforestation after these disturbances differ as well. Such differences might have included changes in soil physical and chemical properties, soil nutrients, site hydrology, availability of propagules for regeneration, and competition with sown agronomic forages. Given these differences, it may be unrealistic to expect wellsite disturbances to reforest similarly to natural fire or timber harvest disturbances, and that the results from the latter disturbances are merely targets to be emulated on wellsites. However, does conceding that it is unrealistic to expect wellsites to reforest similarly to fire or harvest disturbances also concede that "equivalent land capability" has not truly been achieved in reclamation of these wellsites?

Fig. 1.1. Example of differences observed in forest recovery on wellsites relative to wellsites. The foreground shows a grassy wellsite 10 years after drilling and abandonment, while the background shows aspen suckers on a 6 year-old harvest cutblock. (photo: Shane Drozdowski)

The differences on wellsites relative to fire and timber harvest indicate that natural recovery of basic ecological processes such as nutrient cycling (by trees vs. herbaceous cover) have apparently been retarded by several decades. However, the duration of site impairment has not been definitively determined and will remain unknown until some specific causes of poor forest productivity on wellsite disturbances are better understood. Such understanding will assist in adoption of construction and reclamation practices better suited to successfully returning natural ecological function and productivity to wellsite disturbances on forested lands.

1.3 Goals and Objectives

Our overall goal was to contribute to best practices for wellsite construction and reclamation on forested lands within the Green Area of northeastern Alberta that will enable appropriate revegetation and accelerate recovery of ecological processes after disturbance. The desired outcome of which are functioning forests that contribute to both the ecologic and economic health of Alberta. Our approach was to investigate past, present, and potential practices to discover opportunities to enhance reclamation success on boreal wellsite disturbances in terms of ecological recovery. We addressed 3 main questions:

1) What factors or combination of factors lead to impaired site productivity or ecological impairment (and how long do they persist?)?
2) Can these factors be mitigated during the construction phase?
3) If not during construction, can these factors be mitigated during reclamation?

1.4 Scope of Report

Accomplishing reduced footprint is not restricted to effective wellsite reclamation, but can also be accomplished by footprint avoidance and reducing the size of disturbances. In turn, these strategies can be integrated into broader planning strategies such that opportunities for avoiding the creation of footprint, minimizing the size of footprint, and minimizing the intensity and duration of footprint permeate all levels of operational exploration and development plans. While our study focus was specifically on opportunities to reduce footprint intensity and duration through construction and reclamation practices, opportunities for footprint avoidance and size reduction also became obvious during the course of the study, so those are also discussed in this report. The content of the report consists of the following:

- Brief descriptions of the empirical studies we completed and summaries of their results,
- Descriptions of additional operational practices that were not studied empirically,
- Recommendations based on the study results and the additional observations,
- Recommendations on footprint size reduction and footprint avoidance based on discussions with construction supervisors and drilling companies.
- Recommendations regarding integrating the above recommendations into the planning of exploration programs.

While numerous variations in well pad construction are possible in terms of season, disturbance levels, land type, need for borrow materials and so on, we focused primarily on two types of construction. The first was winter-constructed upland wellsites, which are presently the most commonly constructed types on uplands in Alberta's boreal due to ease of access during winter months. The second type of construction examined was the building of permanent clay pads within peatlands from borrowed clay fill. We treated such sites as a change of land use and evaluated treatments aimed at establishing forest vegetation.

To assess factors potentially causing site impairment we studied historic conventional oil & gas wellsites constructed from the 1960's through 1990's, as well as previously constructed (winter 2002/03) *in situ* Oil Sands Exploration (OSE) wells. We applied experimental treatments that examined the effects of various construction and reclamation practices to new-construction OSE sites to determine whether such factors could be mitigated during construction or reclamation. Finally, we evaluated several site prep and tree planting treatments on summer-constructed OSE observation well pads constructed on lowlands from borrowed fill. Since most winter construction of OSE wellsites on wetlands or peatlands are low-disturbance in nature, we did not study construction or reclamation practices on these sites, nor do we make any recommendations regarding them in this document. **This document pertains solely to upland sites or wetland sites that have been converted to upland sites by the introduction and retention of borrowed fill.**

In addition to the empirical measures, we also recorded observations of common practices or procedures that could be problematic to satisfactory natural reforestation but were not directly part of the study design. Finally, because means of achieving footprint reduction are not restricted to reducing disturbance intensity or making reclamation more effective, but can also be achieved by footprint avoidance or reducing footprint size, we assessed opportunities for potential footprint reduction via alternative drilling strategies and greater integration of footprint reduction goals into drilling program development. While the information we gathered was from varied sources, much of the data pertaining to new construction was derived from observations of OSE wellsite construction. However, notwithstanding some variations in practices between OSE and conventional oil and gas, we believe conclusions can be applied to most wellsite disturbance types because the primary effect on the site is that it has been disturbed regardless of the purpose of that disturbance.

We identified certain practices that are impediments to footprint reduction and are common to many operators. Reasons for inconsistencies in practice or use of practices that should be discontinued are varied and may range from lack of awareness among construction contractors to inconsistency in application of regulations among government field staff. Therefore, our intent in addressing such practices was to identify those that occur with relative regularity, thereby providing a reference for industry and regulatory self-examination with the ultimate goal of practice improvement.

Although this report is not a policy document, it is intended to inform policy development, both regulatory and commercial. The recommendations represent an assessment of practices to improve land stewardship within the context of minimizing the footprint associated with energy exploration. We encourage both energy operators and regulators to self-examine practices and initiate change toward integration of footprint reduction strategies into all levels of resource development planning. It is understood that certain constraints, especially safety related practices, can limit what may be accomplished toward footprint reduction. However, constraints may be overcome given a willingness to challenge the status quo. Change will require effort in re-examining how practices or policies impede footprint reduction and in evaluating how footprint reduction strategies might be incorporated without compromising other objectives such as safety.

2.0 The Wellsite Footprint

2.1 Footprint Overview

In situ oil sands delineation or OSE programs in the Athabasca Oil Sands Region where this study was completed generally requires the drilling of at least 16 delineation wells per section (1 sq. mi. or 260 ha; Table 2.1) to provide the necessary geological information to produce the bitumen resource. The bitumen resource will not be distributed uniformly over the area of an oil sands lease. Therefore the oil sands developer will initiate exploratory drilling over a widely dispersed area and then focus within a smaller area as the resource distribution becomes more defined. While the Natural Resources Conservation Board requires a minimum of 8 OSE wells be drilled per section within the lease area (Table 2.1), more than 16 wells could be drilled in the areas of the lease where the bitumen will ultimately be produced. The drilling pattern is determined by spatial statistics that are used to predict the location of the resource below ground. The process is iterative whereby the pattern of initial cores drilled produce information that predict where additional cores should be drilled. The process is repeated until a given level of confidence in the geometry of the below-ground formation is achieved. This process occurs over a number of years.

The OSE program will produce a network of permanent and temporary access roads connecting the forest clearings used for delineation drilling. The clearings range from 0.5 to 1.0 hectare in size. The result is patchwork of clearings (Fig. 2.1) that will contribute to a fragmented landscape without the implementation of appropriate construction and reclamation practices. Although the spatial distribution of wells for conventional oil and gas exploration is not regulated in the same manner as oil sands exploration, the collective footprint can produce a similarly fragmented landscape (Fig. 2.2).

Table 2.1 Minimum numbers of wells per section to be drilled[1] prior to application by a company proposing to produce bitumen in Alberta (excerpt from draft of revised EUB Guide G-23, August 2002).

	Scheme Type	
Deposit / Formation	**SAGD/Vapex[2]**	**CSS[3]**
Athabasca Grand Rapids	tbd[4]	4
Athabasca Wabiskaw-McMurray	16	8
Peace River Bluesky-Gething	12	6
Cold Lake Grand Rapids	tbd	4
Cold Lake Clearwater	8	4
Cold Lake Wabiskaw-McMurray	tbd	4
Paleozoics	tbd	tbd

[1] The minimum number of wells required to be cored per section is four, or 50% of the wells listed in the table, whichever is greater.

[2] Steam-assisted gravity drainage and Vapex—These schemes require a higher level of geologic certainty (and hence a greater drilling density) mainly due to the need to locate horizontal wells close to the bottom of the bitumen zone.

[3] Cyclic steam stimulation.

[4] To be determined.

Notes

- The EUB requires an applicant to have drilled the minimum number of wells per section needed to properly evaluate the reservoir in order to finalize the pad, well, and facility locations within the IDA, prior to submitting its application.
- The EUB may consider requests by an applicant to reduce the minimum drilling requirements. For example, 3-D seismic shot specifically for in situ recovery may qualify for some reduced drilling density, if the applicant can show that the seismic results have been integrated into the resource appraisal of the IDA, and has improved understanding sufficiently to finalize the location the plant, pad and well locations within the IDA. Another example is where significant environmental constraints prevent attaining the required level of drilling, in which case the EUB would consider requests for a lower level.
- It is the applicant's responsibility to meet with the EUB well in advance of filing an application if you intend to request any variance in the above drilling requirements. This will minimize the risk of the application being declared incomplete on the basis of inadequate drilling data.
- Applicants are encouraged to conduct ongoing reclamation and to endeavour to minimize the environmental impacts of exploration.
- Other scheme types will be added as may become necessary.

Fig. 2.1. Satellite image of delineation wells and access routes in a portion of the Long Lake Project near Pushup Lake. Note that the density of delineation wells shown here is approximately one half of the saturation level of 16 wells per section. (Image: Google Earth © 2005 Google, Image © 2006 Digital Globe)

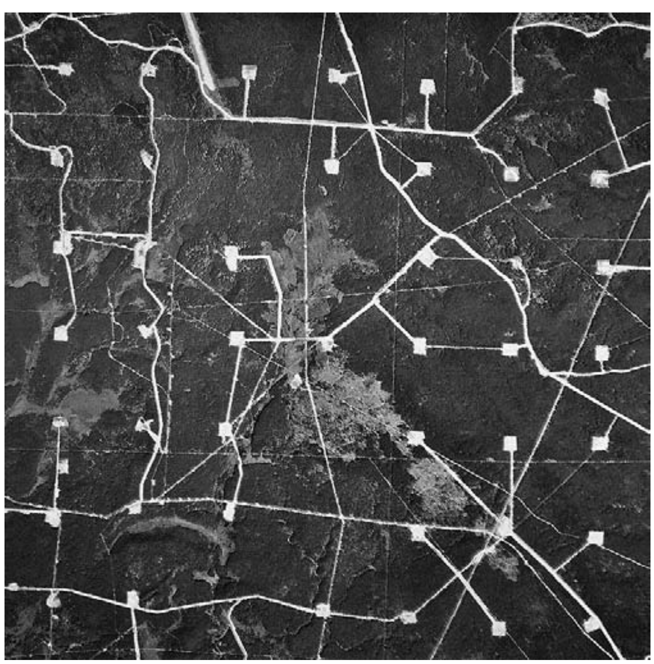


Fig. 2.2. Provincial issue aerial photo showing conventional oil and gas wellsite footprint in west-central Alberta. Well density is approximately 9 wells/square mile.

Forest fragmentation can be potentially deleterious to populations of numerous wildlife species, including caribou, furbearers, and birds. Continued energy exploration and development in the Alberta's boreal without improving the rate of return to natural forest vegetation will increase the rate of forest fragmentation. Our objective is to translate the observations from this research into practices that can help to reduce the size and duration of future footprint expansion, thereby reducing the rate of fragmentation.

2.2 Wellsite Construction

Present OSE delineation well construction and reclamation practices include low disturbance practices as well as fully constructed sites involving complete stripping of topsoil and leveling to build a drilling pad. OSE wells are typically constructed over the winter months when drilling locations are accessible without need for construction of all-season roads. Conventional oil and gas wells drilled in boreal Alberta are also constructed predominantly in winter for the same reason. Both low disturbance and fully constructed practices can be used in conventional oil and gas, but a number of factors such as drilling depth, size of rigs, and expectation of producing wells reduce the likelihood of using low disturbance practices on conventional wellsites in comparison to OSE wellsites. Site construction essentially refers to the preparation of a drilling pad and surrounding workspace for completion of the exploratory drilling. The space required varies but is commonly 70 m x 70 m for OSE sites and 100 m x 100 m for conventional sites, which will accommodate the drilling rig and its associated equipment, as well as any mobile office buildings, vehicles, and safety spacing requirements. Site construction begins with clearing the forest vegetation. Merchantable timber is salvaged and removed to a commercial mill. Non-merchantable timber is either walked down with a dozer or mulched in place.

Full construction of a well pad refers to the stripping and storage (salvage) of surface soil and leveling of subsurface soils to produce a stable and level foundation for operation of the drilling rig. Any excess woody debris from the clearing operation is piled to a corner or edge of the site lease and the surface soils are scraped off with a dozer and also piled to a corner or edge. Usually the surface soils are removed in 2 lifts, the first of which consists of the “topsoil,” while the second consists of all or part of the B-horizon. According to the ASRD (2007) guideline, topsoil is defined as the surface forest floor and all “A horizon” soil (LFH, Ah, Ahe and Ae, according to the Soil Classification Working Group (1998) definition). However if the topsoil depth is less than 15 cm, a total of at least 15 cm must be conserved which includes the topsoil and the B-horizon unless the B-horizon is considered unsuitable due to chemical or physical limitations. Any tree stumps existing on the site are removed during the soil stripping procedure. Next, the sub-soil is leveled with the dozer across the entire area of the lease. For OSE sites and non-producing conventional wells, once drilling is completed and the required information is collected from the well, the well is abandoned by cutting, sealing, and capping the casing at 1 m below the soil surface and then burying it. Reclamation of the lease site consists of recontouring the site to blend with the surrounding topography, followed by replacement of the surface soil layers, woody debris, and any snow initially removed from the surface. Prior to 2002, sites were seeded to either an agronomic or “native” grass species mix after reclamation. Since 2002, sites are commonly left to revegetate naturally. Excess woody debris is usually burned in consultation with SRD staff. Some operators burn excess woody debris during the reclamation phase, while others burn prior to removing the surface soils so that those layers can be used to temporarily bury the charred wood and extinguish any burning embers.

Where the site surface is relatively level to begin with, low disturbance methods can be used and soil stripping and site leveling are unnecessary. However, some operators strip the surface soil regardless of site topography. If soil is not stripped, removal or leveling of tree stumps is necessary. However, stump removal with a dozer can result in soil, root, and seed bank disturbance similar to soil stripping and leveling. Low disturbance methods are ideal on sites where very gentle topography reduces the need for surface leveling, but these methods can also be used where topography is less gentle (Fig. 5.1). In most cases, low disturbance construction is accomplished by using onsite materials such as excess woody debris and available snow to fill in low areas and level the lease. Hauled water can also be used to level the surface by building up lower portions of the lease with ice. A mulcher is often used to level stumps by grinding them to near the soil surface. Other methods of low disturbance drilling are also available, such as using hydraulically self-leveling rigs (see section 5.1). Low disturbance preparation of the drilling pad can minimize or eliminate surface soil disturbance depending on specific site characteristics. Once the well is abandoned, the surface ice is ripped so that the woody debris can be distributed evenly over the site. Finally, the site is left to revegetate naturally.

Low disturbance practices such as the ice or snow pad construction are used primarily on level sites, while fully constructed sites are built where topography is more challenging. On locations where topography is less severe, some combination or variation of the two practices is sometimes used which theoretically should result in moderately disturbed sites. Since completely level sites are relatively rare on upland forested sites, low disturbance sites are relatively rare here also. Therefore most upland sites have at least some level of soil disturbance.

3.0 Study Summaries

We completed eight studies to address questions regarding site impairment factors and their mitigation through construction and reclamation practices:

1. Old Historic Wellsite Retrospective – to identify possible soil and vegetation parameters responsible for impairment of natural reforestation.
2. Recent Construction Retrospective – to assess success of recent practice improvements in reducing impairment of natural reforestation.
3. Soil Stripping Versus Low Disturbance Construction – to compare soil and vegetation responses to these 2 methods of wellsite construction.

4. Effects of Mulching Woody Debris and Mulch Depth on Low Disturbance Sites – to compare the vegetation responses to leaving woody debris whole or mulching and to assess the effects of mulch depth.
5. Single Versus Separated Spoil Piles on Stripped-Soil Sites – to compare vegetation responses to 2 methods of spoil material storage.
6. Root Salvage and Replacement With a Hoe on Stripped-Soil Sites – to compare vegetation responses to targeted root zone soil salvage combined with replacement with a hoe to traditional soil salvage and replacement with a dozer.
7. Replanting Trees on Stripped-Soil Sites – to evaluate the performance of several tree species in reclamation plantings.
8. Clay Pads Left in Place on Wetland Locations – to evaluate several site preparation and planting treatments for revegetating clay pads left in place.

Brief descriptions of the first 7 studies and summaries of their results follow in the remainder of this section. The final study is discussed in section 6.

3.1 Old Historic Wellsite Retrospective

This study was an exploratory exercise to determine whether any factors could be identified with respect to soil and vegetation parameters that could explain the slow return of wellsite disturbances to natural forest. We selected a subset of the sites assessed by Osko and MacFarlane (2001), who observed that the density of trees on recovering wellsites could vary from very few to tens of thousands of trees per hectare regardless of time since abandonment. We therefore stratified previously assessed sites by tree density and age to determine whether any of the soil-vegetation parameters were correlated with tree density or age. We used 16 sites divided into 4 age classes based on date of abandonment as follows: 1 (1975 – 80), 2 (1981 – 85), 3 (1986 – 90), 4 (1991 – 95). There were 3 – 5 sites in each age class. Within each age class, trees were assigned to one of 3 tree density classes (roughly 0, 5000, and 10,000 stems/ha).

Since the ages of the sites varied, construction practices among the historic sites would also have varied somewhat. However, all were upland sites constructed during winter within deciduous-leading forest and abandoned within 1 month of drilling. All sites were about 100 m x 100 m. All sites were cleared of forest vegetation, but rather than salvaging the timber, it was likely all burned. All sites would have been stripped of the upper soil layers for site leveling. However, this soil may not have been replaced on sites in the 2 older age classes given the reclamation criteria of the day. Surface features such as berms and sump pits left in place after abandonment were evident. Large woody debris would have been absent from all sites and all sites were seeded to non-native mixes of grasses and legumes rather than left for natural revegetation.

Soil measurements were completed both on and off-site at depths of 0-15 cm and 15-30 cm. Soil measurements included soil density, soil moisture, texture (percent sand, silt, clay), pH, electrical conductivity (EC), organic matter content, and macro-nutrients. Vegetation measurements included stem density (stems/ha) estimation of all tree species present and percent canopy cover estimation of all shrub and herbaceous species present. An assessment of tree distribution was also made.

Soil density was higher onsite than offsite but within range for naturally occurring forest soils. Soil density commonly increases with depth, which was observed on sparsely treed sites but not on densely treed sites. Soil density did not differ with depth on densely treed sites. There was an increase in clay content of soils onsite compared to offsite, changing the texture classification from silty clay loam to clay loam. This change indicates some mixing of subsurface soils with surface soils during the soil stripping and replacement process. Onsite soils were slightly more alkaline than offsite soils but the increased pH was not limiting. Soil pH may have differed because of differences in the nature of the surface litter and the produced leachate. No differences in soil organic matter were observed between on and offsite locations. Grass cover and species richness were greater onsite than off. Forb species richness increased with tree density onsite, likely due to the effects of shading. Shrub species diversity was greater onsite and increased with onsite tree density.

It is difficult to identify any one factor as responsible for the apparent impairment of forest growth on these wellsites, but it is likely that a number of factors contributed to it. For example, there was some difference in soil density between the wellsites and offsite controls and there did appear to be some relationship between soil density and the number of trees per ha. However, the soil density onsite was still within limits normally observed in undisturbed forest soils. On the other hand, combining increased soil density with increased clay content and poor soil structure (Dave McNabb, pers. comm.) could perpetuate cooler, moister conditions that prevent colonization by the adjacent forest. Another combination of factors contributing to impairment could be the removal of propagules during soil stripping and the seeding of forage grasses and legumes. The removal of propagules, especially suckering roots, reduces a site’s ability to revegetate naturally, while seeding of forages exacerbates the problem by interfering with seedling establishment and competing with any trees that do establish. Finally, while soil organic matter did not appear to differ between wellsites and offsite controls, organic matter was measured only in the mineral soil and did not reflect any contribution of the surface organics to tree growth. The organic layer on an intact forest floor can be very thick in comparison to that on an old wellsite (up to 15 cm or more vs. 1-3 cm). Since soil conservation was not emphasized strongly prior to 1995, removal of this organic material may have been permanent and could have also influenced site capability. The following factors were probably the most influential in affecting the natural reforestation of historic wellsites:

- The forest floor was removed, thereby destroying or disturbing plant propagules and reducing a site's ability to revegetate naturally,
- Forest floor removal would have also reduced the organic material available to support tree growth,
- Soil mixing and compaction during the stripping and replacement process caused poorer conditions for root growth and water uptake
- Seeded agronomic forages further interfered with seedling establishment and growth.

3.2. Recent Construction Retrospective

Soil salvage and replacement criteria for wellsite construction and reclamation were updated in 1995 with an attempt to specify minimum soil salvage requirements (Alberta Environment 1995). However, the wording was confusing: "Salvage a minimum of duff (LFH) plus 15 cm mineral soil unless the mineral soil is unsuitable (e.g., Bnt, bedrock, gravel, rock)." We assume the intent was to salvage all of the LFH and 15 cm of mineral soil, but the wording could be interpreted to mean that a minimal amount of LFH be salvaged with 15 cm of mineral soil. Replacement requirements were to evenly distribute as much of the salvaged soil as possible across the site, but no inspection assessments were required. Additional improvements were recognition in 2002 of the value of large woody debris and the negative competitive effects of seeded grasses (Alberta Environment 2002, 2003). In response, we examined natural revegetation on OSE wellsites constructed during winter 2002/03 to determine whether the updated soil salvage practices and the absence of seeded forages may have had on reducing the impairment factors previously identified in the old historic site assessments.

We selected 13 upland OSE sites within maturing to mature deciduous-leading forest, constructed according to the stripped-soil method described in Section 2.2 and left for natural revegetation. We completed the same soil and vegetation observations as for the old historic site assessments, with the addition of sulfate, phosphorous, potassium, and nitrate-nitrogen analyses of soils.

Some improvement in soil conditions were evident in these sites relative to the old historic sites. Onsite soil density was either the same or less than offsite density. Soils also contained less clay onsite than offsite, but this did not result in a difference in texture class. Finally, nitrogen and organic carbon content of soils were also slightly higher onsite than off. These observations are likely due to some mixing of salvaged LFH with the mineral soil and the mineralization of nitrogen that typically occurs after disturbance of forest soils (Vitousek et al 1979, Vitousek and Melillo 1979). Other differences between onsite and offsite soils were slight increases in pH and electrical conductivity, but these measures remained well within normal ranges.

Vegetation differences were evident between recent sites and older historic sites, but a number of similarities were also shared. Herbaceous vegetation differed substantially in terms of species composition, characterized by the absence of non-native species on the 2002/03 sites. Grasses dominated older sites more, whereas the newer sites had a greater variety of forbs but still maintained a substantial grass cover. Overall, tree density was similar between the older and newer sites, but species composition differed somewhat. Aspen and white spruce density were somewhat higher on the 2002/03 sites, while balsam poplar density was higher on the older sites. Another similarity between the recent and older sites was the distribution of colonizing trees. In both cases, there was recruitment along the lease edges, but little penetration into the middle of the lease (Fig. 3.1).

a)

b)

Fig. 3.1. A typical pattern of natural reforestation on stripped-soil constructed wellsites: a) a gas well drilled, abandoned, and seeded to agronomic grasses and legumes 25 years prior to the photo has a dense growth of newer trees around the edge of the lease, but the remainder of the lease is treeless; b) an OSE well drilled, abandoned, and left for natural revegetation 5 years prior to the photo shows a similar pattern of dense growth from the edge but no recruitment on the rest of the lease. (photos: a) Lance Lazaruk, b) Terry Osko)

Despite, improvements in soil conditions and elimination of competition from seeded forages, wellsites still appear to be at risk of remaining as meadows rather than reforesting on their own. What then are the significant factors impairing natural forestation on the wellsites studied, assuming soil compaction, mixing, nutrient status, and competition from agronomic vegetation are not? The only factor remaining from the assessment of older historic sites is the removal of the forest floor and subsequent damage or redistribution of tree propagules. However, while competition from non-native herbaceous species may have been eliminated, competition from native herbaceous species may still be a factor. Apparently, the key to ensuring satisfactory natural reforestation of stripped-soil sites is to encourage tree establishment by reducing propagule loss or enhancing propagule introduction, combined with discouragement of excessive colonization by herbaceous vegetation.

3.3 Soil Stripping Versus Low Disturbance Construction

Low disturbance wellsite construction is a recently adopted practice. The incorporation of onsite woody debris in combination with ice and snow is probably the most common method, but other methods such as the use of hydraulically self-leveling rigs can also be used. The extent to which these practices are adopted varies among practitioners and the energy companies contracting them. Slope and topography are most often cited as the factors limiting to the use of low disturbance construction methods. The accepted limitation posed by slope also varies widely among practitioners, which may suggest an incomplete understanding of the use and application of these techniques.

We compared the iced-in method of low disturbance well pad construction with the conventional soil stripping method to determine whether low disturbance construction provides any benefits in terms of natural regeneration of forest vegetation. We selected 5 low disturbance and 5 stripped-soil sites for study, all of which were constructed within deciduous-leading upland forests during the winter of 2003/04. Excess woody debris on the stripped-soil sites was burned, leaving a limited amount of slash after final reclamation. Woody debris on the iced-in sites was ground into a mulch of wood chips, which remained on site and were spread over the lease at various depths upon final reclamation. We planted 3 tree species (aspen, balsam poplar, and white spruce) on one randomly selected half of each of the sites. We collected onsite and offsite soil samples for analysis of soil density, texture (% sand, silt, clay), electrical conductivity, pH, % organic carbon, % organic nitrogen, and carbon:nitrogen ratio. We measured annual growth of planted trees by recording root collar diameters and tree heights after initial planting and every spring thereafter for 5 years. We also completed annual vegetation inventories over 5 years, estimating canopy cover for herbaceous and shrub species, while estimating stem density (stems/ha) for tree species.

Soil carbon and nitrogen were both higher on the stripped-soil sites than on the low disturbance sites, again likely due to some mixing of the LFH with the mineral soil, as well as the nutrient release effect associated with disturbed soils as previously indicated (section 3.2). Soil carbon and nitrogen were higher on the stripped-soil sites than the low disturbance sites overall, but did not differ between control and onsite locations. Therefore, it is not apparent that construction practice influenced soil carbon or nitrogen. Soil pH and electrical conductivity did not differ between construction practices, but both were slightly higher onsite than offsite. In neither case were the values outside of normal ranges for aspen-leading forested soils. Clay content was higher overall on the low disturbance sites, while silt content increased slightly onsite for both construction practices. Overall, we observed little influence of construction practice on the soil variables measured.

Survival rates of planted trees differed only for balsam poplar, which had better survival on stripped-soil sites. Aspen height growth did not differ between construction practices, but aspen diameters were slightly bigger on stripped-soil sites. A similar pattern was observed for balsam poplar and white spruce.

The density of naturally colonizing trees was much higher overall on low disturbance sites than stripped-soil sites. Dominance of aspen on low disturbance sites was primarily responsible for this difference (Fig. 3.2). Aspen density was 10,000 to 15,000 stems per hectare on the low disturbance sites, compared to a few hundred stems per hectare on the stripped-soil sites. There were no differences in stem density between construction practices for any other species. The other species together totaled approximately 3000 stems per hectare on both the low disturbance and stripped-soil sites.

a)  b) 

Fig. 3.2. Vegetation recovery during second season after construction: a) OSE site constructed with soil stripping, vegetation consists primarily of native and non-native grasses and legumes; b) piezometer site constructed by low disturbance method, vegetation consists primarily of aspen suckers. (photos: Terry Osko)

3.4 Effects of Mulching Woody Debris and Mulch Depth on Low Disturbance Sites

Grinding excess woody debris into mulch is a common wellsite construction practice used in forested for various reasons. Primarily, it is an effective way to clear the site of non-merchantable timber and to level stumps that might cause unnecessary soil disturbance if removed with a dozer. Another benefit of mulching is that the wood chips produced can be used as construction material together with ice or snow to assist in leveling the site. Mulching slash also reduces the space required for woody debris storage on site during drilling and eliminates the hazards of burning. However, a given volume of mulch on a site may have more deleterious effects on recovering vegetation than the equivalent volume of whole wood because mulch produces a continuous layer over the soil. While whole logs and tree limbs laid over the site at various angles might overlap and produce a deep layer, this arrangement also leaves numerous spaces where the surface soil is exposed. Furthermore, the mulch creates a uniform surface whereas whole slash creates a rough surface with a greater number and variety of microsites for establishment of various plants. The continuous layer of wood chips over a site can potentially interfere with regrowth of desired vegetation by reflecting solar input, as well as insulating the soil if spread too deeply.

We compared the response of naturally regrowing vegetation to mulch or whole slash applied to the surfaces of sites constructed with low disturbance methods. We examined 6 sites, each of which were level and previously vegetated by maturing mixedwood forests. Well pads were constructed from ice and woody debris without stripping of any surface soils. Woody debris on 3 of the sites was mulched, while woody debris on the remaining 3 sites was left whole.

We also compared the effects of deeply and shallowly applied mulch on resulting regrowth of naturally recolonizing trees and herbaceous vegetation on 3 additional sites of similar vegetation cover and construction. On these sites, the mulched woody debris was replaced on each site in alternating strips of deep (>10 cm) and shallow (<5 cm) mulch.

Regrowth of trees was variable within the mulch and slash treatments, but the numbers of poplar and birch trees per hectare were significantly higher on slash treatments than mulch treatments. Aspen and spruce densities were similar between treatments. No differences were observed between treatments with respect to either herbaceous species cover or richness.

Responses to mulch depth were much more pronounced. Again, recolonizing tree density was highly variable among the sites, but overall tree densities were lower on deep mulch treatments (Fig 3.3). Herbaceous vegetation response was more uniform among sites, with vegetation cover and species richness both much lower on deep mulch treatments compared to shallow treatments.

Fig. 3.3. Contrast in natural tree regrowth between shallowly (right) and deeply (left) applied mulched woody debris. (photo: Terry Osko)

3.5 Single Versus Separated Spoil Piles on Stripped-Soil Sites

Some operators attempt to save space on the lease by piling all the strippings (slash, duff layer, and surface soil) in a single, albeit layered, pile. This practice is practical for effectively using lease space and is convenient for extinguishing burning slash piles. However, the resulting vegetation recovery was not known. On the one hand, mixing of the organic layers with mineral soil might improve soil fertility and improve growth of planted trees. On the other, plant seeds that would normally occur at or near the soil surface in a non-disturbed environment become buried. Some mixing of surface layers is unavoidable even when replacing strippings that are piled separately. However when piled together, it is impossible not to increase this mixing.

We compared responses of recolonizing vegetation as well as planted trees between sites using single versus separated spoil piles. All sites were previously vegetated by maturing mixedwood forest with gentle to moderate topography. Four sites using single spoil piles were compared with 3 sites using separated piles.

Naturally recurring tree sapling density (stems/ha) was lower on sites where strippings were placed in a single pile rather than piling spoil components separately. Furthermore, single pile stripping negatively affected survival of planted aspen and birch seedlings. By contrast, planted poplar survival was better on single pile sites. Spruce survival was not affected. Growth of spruce and birch were negatively affected by placing strippings in a single pile. Seedlings of these species grew taller on sites where strippings were piled separately rather than in a single pile.

3.6 Root Salvage and Replacement with Hoe on Stripped-Soil Sites

As indicated in section 3.2 above, the primary problem with stripped-soil construction is the destruction of suckering roots, which substantially impairs reforestation via natural recolonization by trees. Root destruction occurs as part of the soil stripping, storage, and replacement process. While ASRD has provided direction with respect to soil stripping (ASRD 2007), operators untrained in forest soils often mistake surface organics for topsoil when interpreting soil layers solely on the basis of colour. When soil colour is used to guide soil stripping, the first pass typically removes the surface duff or LFH layer, while the second pass removes the uppermost mineral layer, usually a Luvisolic Ae. Depending on the depth of this layer some of the B-horizon may be removed as well. The lease is then leveled using the lower B and C-horizon material. Unfortunately, the bulk of suckering roots exist in the space near the interface between the surface duff layer and the upper mineral horizon (Fig. 3.4). As such, this layer is subjected to scraping by the dozer blade during stripping, as well as dozer traffic as the dozer moves back and forth to pile the strippings and remove the next layer. In addition, the roots in the storage pile are exposed to freezing and desiccation due to the small amount of soil covering them. Finally, the roots are again exposed to freezing and dozer traffic when the pile is pushed back over the lease with the dozer. In the end, most of the roots are scraped and driven over several times. Furthermore, much of the original root mass works its way up to the surface as the soil is being pushed across the lease, thus they are not re-buried and remain on the surface of the lease where they expire.

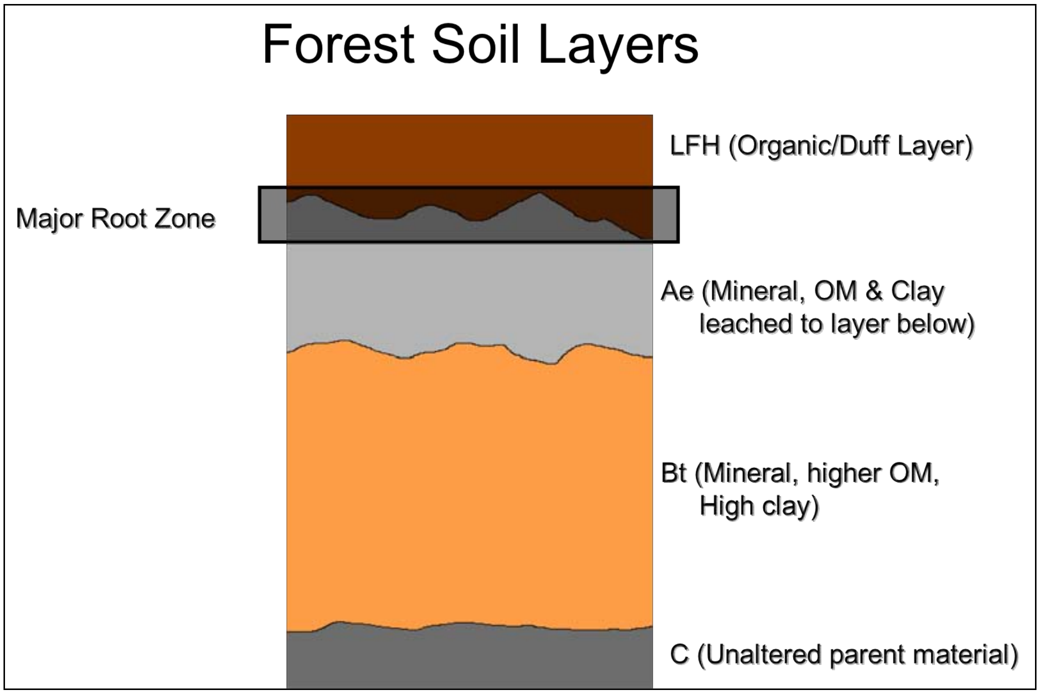


Fig. 3.4. Schematic of typical upland forest soil indicating location of most suckering roots (shaded area).

We tested an alternative soil stripping approach whereby, after slash removal, the first cut is made deeper such that the entire suckering root zone was taken in a single pass. This pass included both the surface duff layer and part or all of the first mineral horizon (Fig. 3.5), and the root-soil material was stored in a windrowed pile along one edge of the lease. The remaining mineral soil strippings were used to level the lease or stored in a separate pile adjacent to the root zone pile, producing 2 or 3 piles on the lease (slash, root zone, and mineral soil, Fig. 3.6). The layers were then spread over the lease in the reverse order after abandonment of the well. However, the root zone and slash were spread over the lease using 2 track-hoes rather than a dozer (Fig. 3.7). This procedure reduces traffic over the roots, reduces exposure of roots to freezing and desiccation, and facilitates better placement of the roots in the soil (Fig. 3.8). In addition, a rougher lease surface is produced that provides a variety of micro-sites for plant establishment, reduces mixing of slash and woody debris with surface soil, and enables more even distribution of surface soil over the site than observed when dozers are used.

Fig. 3.5. Rooting zone and combined layer to be stripped in a single pass and stored together rather than 2 passes and stored separately. (photo: Terry Osko)

Fig. 3.6. Separate slash pile and rooting zone pile with mineral subsoil used to level lease. (photo: Terry Osko)

Fig. 3.7. Progressive replacement of rooting zone with 2 trackhoes. (photo: Terry Osko)

Fig 3.8. Small mass of suckering roots sprouting new growth on OSE wellsite recently reclaimed using the "root salvage" method. (photo: Terry Osko)

We compared site recolonization by trees and shrubs on sites constructed in this manner to stripped-soil constructed sites where specific attention was not paid to the depth of root layer in the soil stripping and salvaged soil was replaced with a dozer instead of a hoe. While shrub density was similar between construction treatments, shrub diversity was higher on the sites where the root salvage technique was applied. The number of trees growing per hectare was higher on the root-salvaged sites.

3.7 Replanting Trees on Stripped-Soil Sites

As described above, natural re-colonization by trees and shrubs seems to be impeded by the lack of viable sprouting roots because of removal, damage, or destruction of roots during the construction and reclamation process. Furthermore, herbaceous vegetation can quickly colonize stripped-soil sites, thereby preventing or competing with natural tree establishment. Thus, stripped-soil constructed sites can potentially remain relatively devoid of trees for decades.

The surest method for establishing trees on stripped-soil constructed sites is to plant with site-appropriate tree seedlings in the first growing season post-construction

We planted several tree species on one half of each of the sites mentioned in sections 3.3 – 3.5 above. Aspen, balsam poplar, and white spruce were planted on the sites discussed in section 3.3, while these 3 species as well as paper birch were planted on the sites discussed in sections 3.4 and 3.5.

All species used in our study performed reasonably well on all site types. Survival of all species we tested was good to excellent in all site applications, though the survival of poplar was the lowest among species tested. On the other hand, surviving poplars had the most robust growth and competed well against re-colonizing herbaceous vegetation (Fig 3.9). Poplar survival was probably lower due to planting unrooted cuttings rather than rooted cuttings (a cutting with an established shoot and root system). While initial aspen survival was good, subsequent growth was disappointing. Aspen trees remained small and tended to grow very branchy without gaining much height. A potential advantage of aspen however, is that many of these small saplings appeared to be suckering, which would increase the stand density. We did not assess jack pine in the OSE wellsite experiments, but it performed well in plantings on borrow pits and clay pads left in place (section 6).

Fig. 3.9. Poplar saplings during fourth season of growth after planting on a cut & fill constructed OSE wellsite. (photo: Maggie Glasgow)

In addition to the planting completed with the above studies, we also planted poplar, birch, pine, and spruce on three pre-existing stripped-soil sites that had surface materials (mineral Ae horizon, duff, slash) rolled back over approximately two-thirds of the surface, while one third remained as exposed subsurface soil. The sites were previously vegetated with maturing mixedwood forest. Half of the area of rolled back material on each site was further treated by in-place grinding of the existing slash into mulch. The trees were then planted into each of the three treatments (Roll Back, Mulch, Exposed Sub-Soil) on each of the three sites. There was no difference in poplar growth among the three treatments. Birch grew best on the exposed sub-soil, while pine and spruce grew best on the rolled back (but not mulched) area. Natural shrub regrowth was dense on the rolled back areas and absent from both the mulched and exposed sub-soil areas.

4.0 Additional Observations

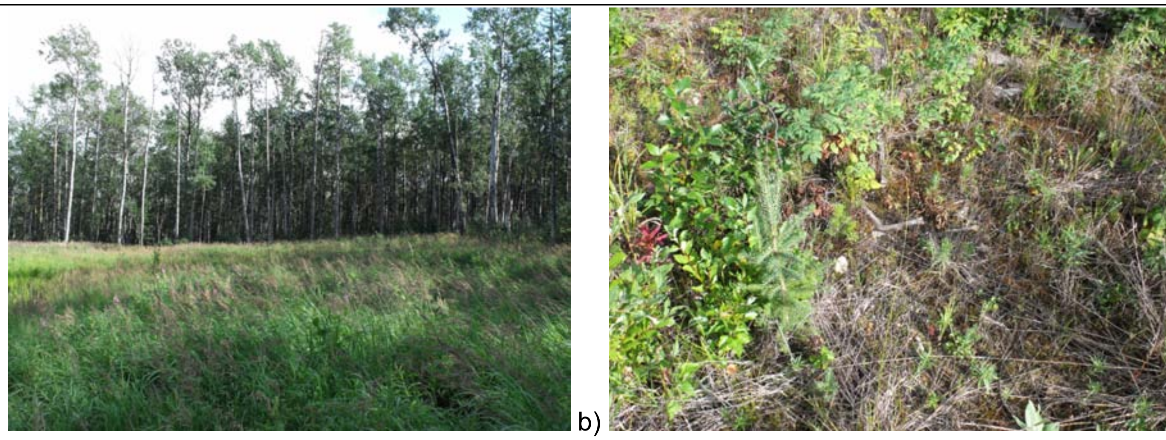
In this section we discuss some additional observations of practices, procedures, or site conditions that were not studied directly but are worth mentioning because, by their regular occurrence, they represent opportunities for improved operations.

4.1 Mulch/Soil Mixing on Stripped-Soil Sites

The insulating nature of mulch is a problem regardless of site construction method. However, on stripped-soil sites, an additional problem is the mixing of wood chips with soil during the reclamation process of replacing soil and woody debris back over the site surface. Thos problem is exacerbated when a single spoil pile has been used. Mixing of soil with wood chips also occurs when woody debris is ground in-place. This results in a surface layer that is no longer a soil per se, but rather, bits of mineral soil filling voids within a wood chip matrix. While tree seeds may germinate on this mixture, the environment is not conducive to continued growth and survival of the seedling due to over-aeration, susceptibility to drought, and poor root anchoring. Finally, the wood chip mulch tends to reflect a lot of heat. The reflected heat is problematic on sites that need to be planted because the small tree seedlings can become scorched and die.

4.2 Soil Moisture/Water Table

We observed that some sites appeared to be more susceptible to becoming dominated by grass communities than others, with the common attribute among them appearing to be poorer drainage. Sites that were in topographical lows, were level but in an area of high water table, or had finer-textured soils seemed to be quickly colonized by marsh reed grass (*Calamagrostis canadensis*) and raspberry (*Rubus idaeus*), with little apparent potential for future colonization by trees or other shrubs (Fig 4.1a) On the other hand, sites with coarser soils or with a deeper water table seemed to revegetate with more diverse communities that included a variety of herbaceous species, shrubs, and trees (Fig 4.1b). While this observation was more common on stripped-soil sites, we also observed this on low disturbance sites with deep mulch layers in areas of shallow water table (Fig 4.2). We have not yet confirmed the relationships between grass dominance and soil drainage empirically, but are presently developing an analysis to do so. Pre-construction knowledge of site drainage or moisture conditions could be used for prescriptive planning of construction and reclamation options. Perhaps even a simple indicator like a pre-disturbance ground cover estimate for marsh reed grass could provide sufficient warning that a site may be at risk of grass dominance (Leiffers et al, 1993).



a) b)

Fig. 4.1. Contrast in natural revegetation apparently based on soil moisture or site drainage. The two photos show extremes of a range of observations on stripped-soil constructed OSE sites 5 years after reclamation: a) a site occupying a topographic low that is dominated primarily by marsh reed grass; b) a hilltop site is vegetated by a variety of both woody and herbaceous species. Raspberry and willows can be more abundant on sites drier than 'a', while grasses and forbs may be more abundant on sites wetter than 'b'. (photos: Terry Osko)

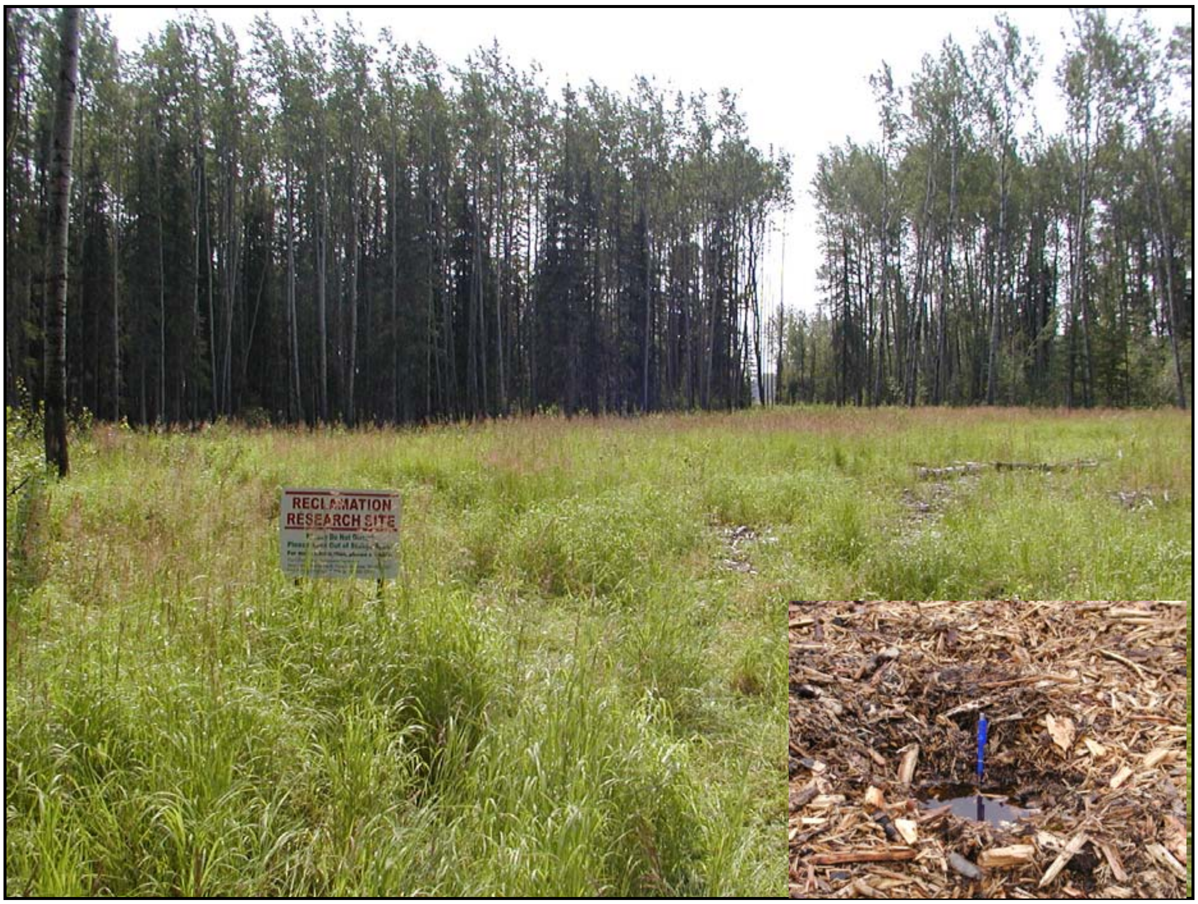


Fig. 4.2. A level upland site of low disturbance construction at a location with a high water table. Removal of the tree canopy contributes to an elevation of the water table and soil cooling, while a dense mat of woody mulch (inset) exacerbates the cooling resulting in the promotion of dominance of the site by grass. (photos: Terry Osko)

4.3 Partial Stripping of Leases

A common practice observed on sites with gentle to moderate slopes is to strip only the upslope portion of the lease and transfer the soil from that location to the lower slope position in order to level the lease. After the well is abandoned, the material that was deposited down slope is then moved back to the upslope position. In theory, only half of the lease area is disturbed because the lower slope position was only temporarily buried and then re-exposed without damaging the root zone. In practice however, the results are quite similar to having disturbed the entire lease surface. While it is true that the root zone remains intact on the down slope side of the lease, removal of the upslope material is often not complete, thereby leaving the intact root zone and original forest floor buried by various depths of material. On mulched sites, this material may consist of 20 – 30 cm of the mulch-soil mixture described in section 4.1 (Fig. 4.3). On non-mulched sites, we have commonly observed the forest floor buried under 15 – 20 cm of sub-surface mineral soil. Permanent burial of the forest floor with this material will not only severely impede suckering of trees and shrubs that would have otherwise sprouted vigourously, but will also prevent the growth of the herbaceous plants normally occupying the forest floor. Furthermore, the material left on the surface will encourage primarily weedier species that will compete with the establishment of desirable plant species.

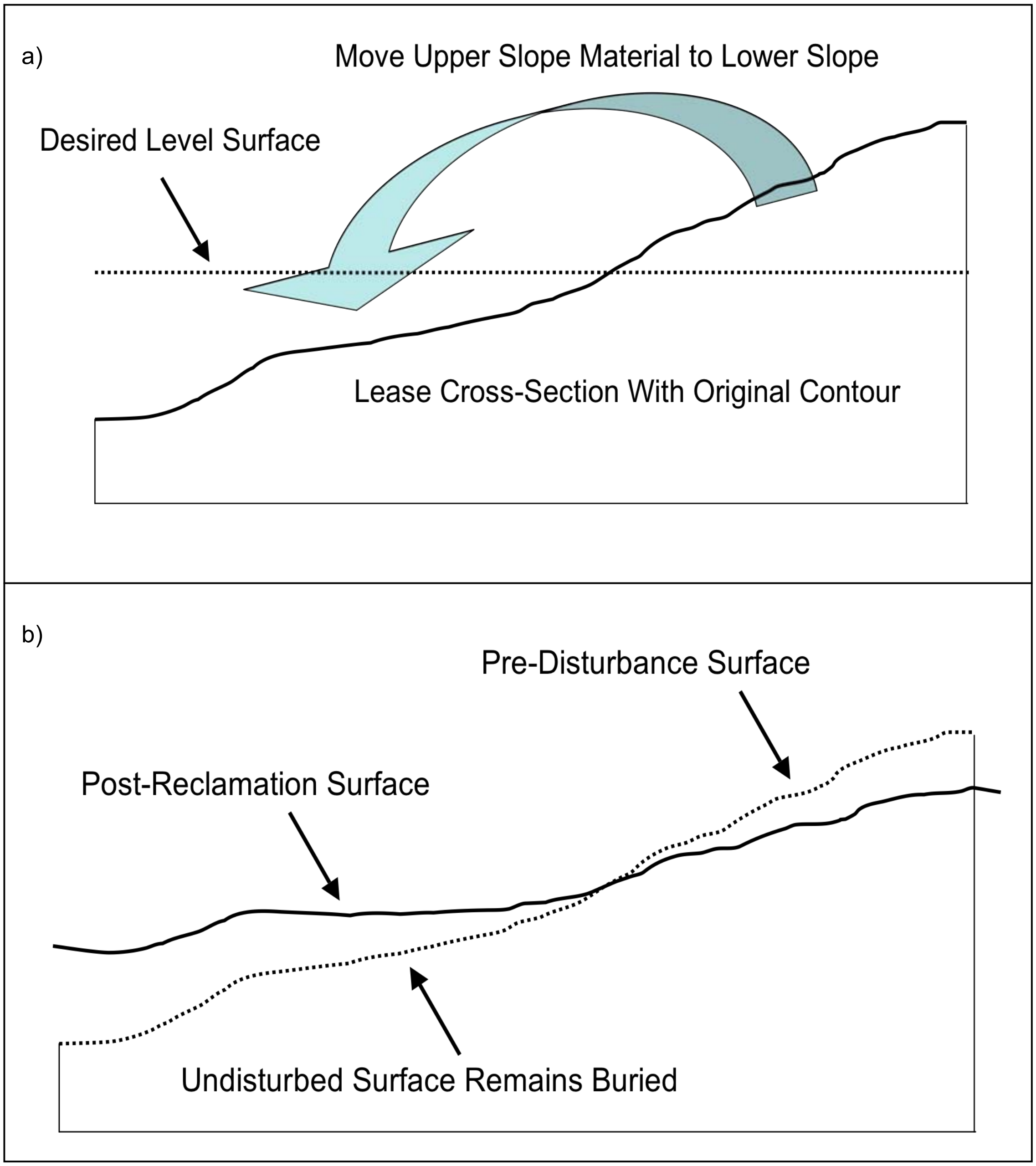


Fig. 4.3 Illustration of partial stripping of nearly level to moderately sloped sites: a) only the upper slope section of a lease is stripped. Soil material from the upper slope is moved to the lower slope to temporarily level the site; b) after abandonment of the well, the material deposited on the lower slope is returned to the upper slope. Theoretically, the lower slope will not have been disturbed. In practice however, incomplete removal of the fill material can leave the original forest floor buried, which can result in impairment similar to soil stripping.

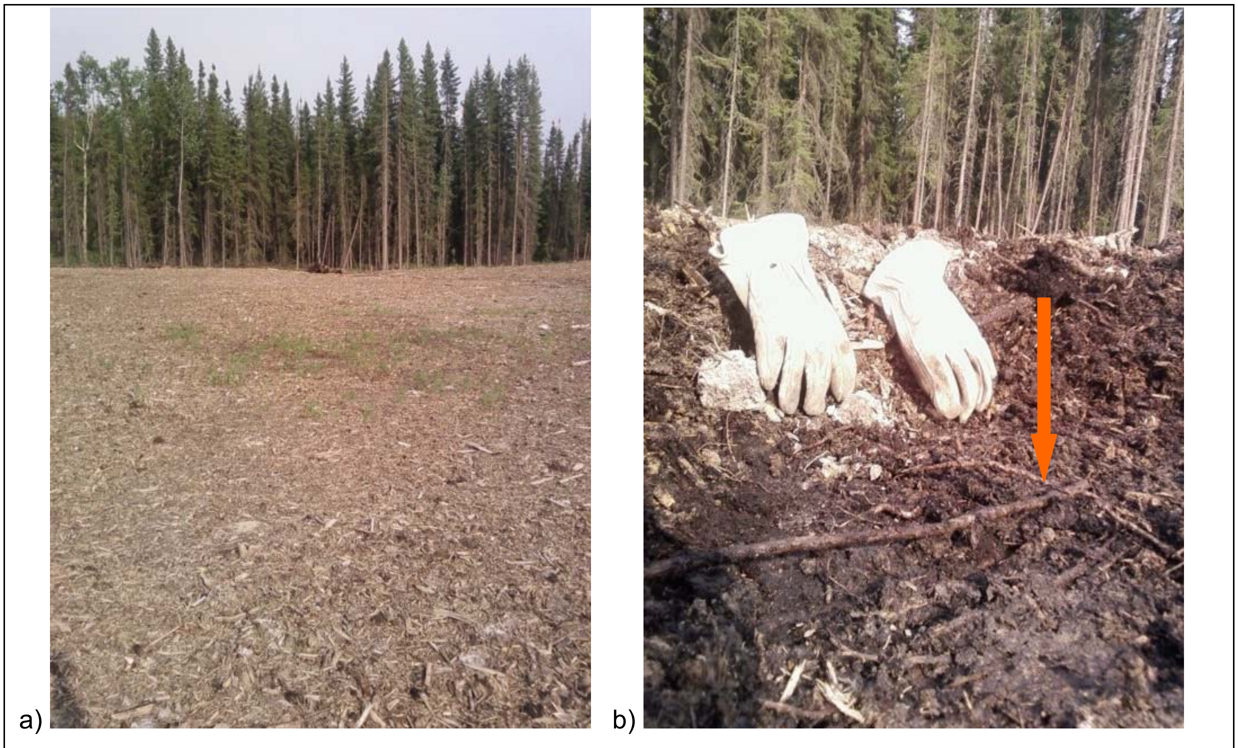


Fig. 4.4. Mix of mulch and soil strippings over a recently reclaimed nearly level OSE wellsite: a) an overview of the site with the upper slope in the foreground with soil strippings and mulched woody debris re-deposited. In the background soil material was incompletely removed. In mid-photo, the site is greening up where the site was minimally disturbed and not left buried. This is represented in Fig. 4.3b where the pre-disturbance surface and post-reclamation surface lines cross; b) intact forest floor (arrow) buried by excessive fill material on lower portion of site from which fill material was incompletely removed. Excessive construction costs and poor forest recovery could have been avoided on this site by using low disturbance practices discussed in section 5 rather than moving soil material to overcome the minor slope of this site. (photos: Terry Osko)

Partial stripping of leases should only be practiced if the material moved to down slope positions can be and is removed entirely to re-expose the intact forest floor. However, given the capabilities of drilling rigs to operate on non-level surfaces, it is wholly unnecessary to employ this practice on gentle to moderate slopes where low disturbance practices should be applied. Partial stripping might be a potential practice on extreme topography in order to reduce changes in elevation such that a hybridized low disturbance approach might be taken. However, in cases of such extreme topography, it may be better to fully construct the location by soil stripping or to relocate the top-hole position to a site with friendlier topography. Given the number of options available to avoid partial stripping of sites, this practice should be the last option (see section 5). Low disturbance solutions, including the use of self-leveling rigs or iced-in construction on gentle to moderate slopes should be considered first. Where topography is severe, moving the drilling location should be considered.

4.4. Salvaged Soil Replacement

We regularly observed instances of uneven surface soil replacement on stripped-soil constructed sites, where some locations on a lease would have a cover of 30-40 cm of surface soil, while other areas of the same lease may have been covered with 5 cm or less. Worst-case scenarios were occasional instances where surface depressions on a lease were filled with more than one meter of surface soil. Such poor distribution of surface soil wastes valuable nutrients by concentrating them in one location where they might decay anaerobically. Alternatively, potentially valuable subsurface layers might be buried. A difficulty with winter construction, especially if snows are frequent, is that it may de difficult for operators to determine the depth of soil material being distributed if it is mixed with snow. What might appear to be adequate depth of material may not be so once the snow melts away. Greater care should be taken for ensuring surface soils are properly re-distributed, especially on complex slopes.

4.5 Inconsistent Vision of Reclamation Outcomes

During the course of this study we observed a lack of consistent vision among those involved in the construction and reclamation process with respect to expected reclamation outcomes. This observation included energy company representatives, construction contractors, and regulatory agents. While eventual reclamation certification appeared to be the guiding principle by which all involved were operating, there remained inconsistency among individuals and organizations in terms of what practices should be used and what the final reclaimed product should look like. For example, a construction contractor working for one energy developer constructed all upland sites by stripping soil regardless of how level the site was. Meanwhile, a contractor working for another energy developer used a low disturbance method (building pads from snow and woody debris) on all level sites, as well as sites that had gentle slopes or shallow depressions (see Fig. 5.1). However, a personnel change in construction supervision for this developer resulted in stripped-soil construction on sites with gentle slopes or shallow depressions.

Another example was the burning of nearly all slash from every site by a particular contractor (see Fig. 5.3). The contractor indicated this was done to avoid being penalized by SRD inspectors for leaving too much slash on site. It was not clear whether the contractor was using his own judgment regarding the amount of slash to burn or whether he was explicitly instructed by an SRD agent to burn the amounts he did. In any case, the implication is that either he or the local forest officer did not consider slash to be beneficial to reclaimed sites.

We also observed that while common language might be used among parties involved in the construction and reclamation process, interpretation of that language was not always consistent among the parties. For instance, equipment operators accustomed to working on agricultural lands were susceptible to misinterpreting what was meant by “topsoil,” thereby potentially resulting in suboptimal soil salvage, especially when operators strip soil on the basis of colour change. Finally, an additional source of inconsistency was mixed messages received from regulators, particularly with respect to the practice of mulching woody debris. Some agents promoted the practice, while others condemned it.

These observations also imply an absence of adequate quality control on the part of the energy developers. One would expect that if a clear vision of the expected reclamation outcome was communicated to the contractors, the contractors would deliver that outcome or expect to be replaced. Given the range of outcomes observed for similar site types, the developers in these cases either lacked a consistent vision or did not communicate it effectively to their contractors. While the observed inconsistencies may not result in failure of reclamation certification applications, they do result in poorer results than are otherwise possible. Establishing consistent (and in some cases raised) expectations of reclamation outcomes, as well as a process of clearer and more specific communication both within companies and among agencies, is desirable.

5.0 Construction and Reclamation Recommendations

5.1 Maximize Low Disturbance Construction Practices

It follows that the less a site is disturbed the easier and less costly it will be to achieve recovery. This was demonstrated by the observations made during this research. Therefore, a fruitful strategy for footprint reduction is to minimize the surface disturbance required to construct individual drilling pads for OSE or conventional oil & gas wells as much as possible. The obvious benefit is an acceleration of natural revegetation to a desired plant community within years rather than decades. However, there are operational benefits also. Costs of building low disturbance well pads are cheaper. Building pads from ice and snow can save approximately $15,000 per OSE well location versus stripped-soil construction (Dan Hommy, Nexen Drilling Construction, pers. comm., Vern Moulton, ConocoPhillips Drilling Construction, pers. comm.). On a 200 well winter program, $3M could be saved or invested into alternative low disturbance technologies. Alternative practices such as using self-leveling drilling rigs may enable further savings. Self-leveling rigs may reduce construction time, potentially increasing the number of holes drilled per winter or helping to ensure completion of drilling programs within winter timing constraints.

Low disturbance lease construction observed during our study was primarily accomplished via construction of drilling surfaces from ice or packed snow using the iced-in method described in section 2.2. While this practice is effective, its application appears to be restricted primarily to completely level sites. It can be used on gently sloping sites, but our observation was that it is not applied consistently. Some operators employed this method on slopes of about 2% while others, even within the same company, stripped soil in order to level sites with much less slope, as discussed in section 4.5. One of the companies used snow and woody debris to successfully fill in a 1 m drop in elevation along one edge of a lease (Fig 5.1). While relying on available snow for construction material may limit what can be accomplished, snowmaking equipment can be used to produce up to 100 m^3 of snow per hour (Carter Industries, Ltd.), thereby reducing reliance on snow available on site. Snowmaking has been used for building ice bridges and other oil-field construction for over fifteen years (Kurt Kadatz, Shell Canada, in Stolte 2009). While operators claim constructing a well pad with ice made from hauled water is dependent on sufficiently cold temperatures (Dan Hommy, Russ Gable, Nexen Drilling Construction, pers. comm.), artificial snow can be made at temperatures as high as -1°C (Carter Industries, Ltd.). Both methods do require a reliable source of water, but surface water is readily available at most locations in boreal Alberta. Furthermore, once it is made, some snow and even mulched woody debris could be transported and reused for construction material on nearby locations. Reusing such materials is a particularly applicable on OSE leases where many sites may be drilled in close proximity, but is probably less applicable on conventional oil or gas leases.

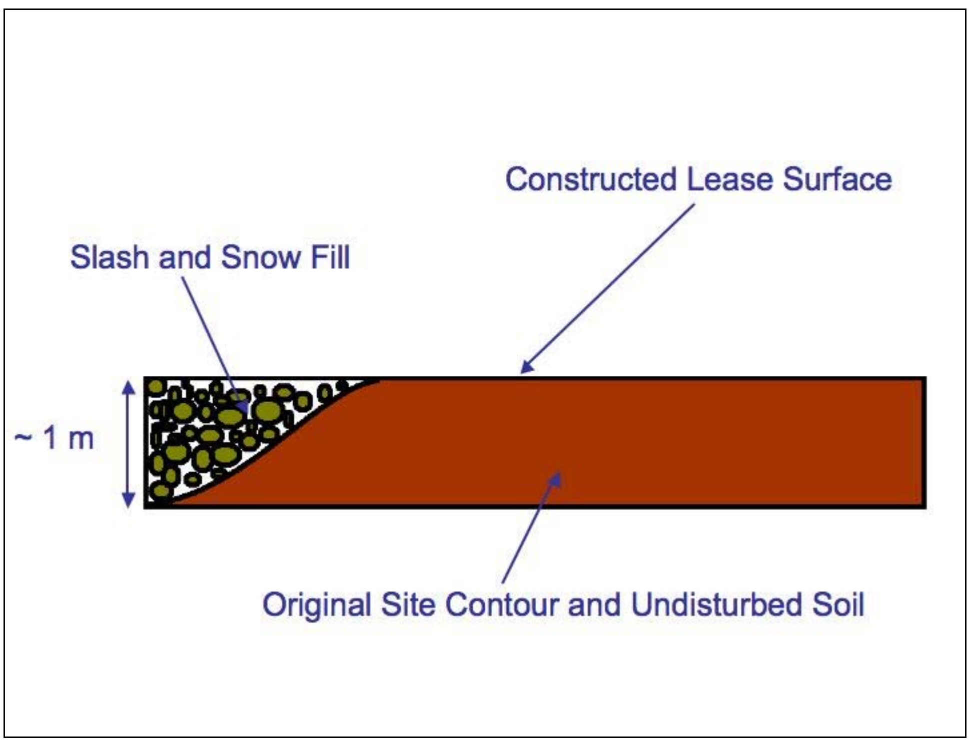


Fig. 5.1. Not-to-scale illustration of cross-section of Nexen OSE constructed at 5-29-85-6-w4. The lease area was fairly level except for a drop along the northern edge of the lease. This dip was filled in with whole woody debris and snow available on site to produce a level surface for the full 70 m width of the lease.

As mentioned previously, self-leveling rigs are another potential tool for achieving minimal disturbance of soils on constructed wellsites. Drilling contractors stated that stripped-soil construction of OSE well pads was largely unnecessary even when working on non-level ground and that present rig technology can provide a number of possible alternatives. Jim Hamilton of Precision Drilling remarked that if the drilling contractor knows in advance that they will be working in non-level ground conditions, they can pre-prepare the sub-structure of the rigs with hydraulic jacks so that they can be leveled despite onsite elevation differences. Furthermore, the rigs can be oriented onsite to best accommodate addressing the topographic conditions encountered. Similarly, Don Golddale of Trailblazer Drilling and Akuna Drilling stated that his rigs have operated in conditions where there was a 1.8 m change in ground elevation over the 18 m length of the rig platform (10% slope). Rod Schmidt of Treo Drilling Services Partnership echoed the above remarks, stating that any of their equipment used for drilling to depths of less than 1500 m is designed to set up on any terrain. Glen Theissen of Encore Coring and Drilling Inc. gave the most conservative response, suggesting that 5% would likely be the maximum slope acceptable for them to operate on. However, this still represents 3.5 m of elevation difference across a typical 70 m by 70 m lease, far more than any slopes encountered on low disturbance wells in our study and far more than encountered on many stripped-soil sites. While drilling on 10% slopes is not advisable, particularly because of safety concerns, the capability to do so is testimony to the ability to reduce the degree of soil disturbance in wellsite construction. On the other hand, perhaps portable platforms that adapt to site topography and are secured to the base of drilling rigs could be designed to provide a safe, level, working surface for drilling rig operators. The self-leveling capabilities of drilling rigs can also relieve some of the weather and water availability constraints associated with iced-in construction of wellsites. Because the rig can level itself to accommodate onsite elevation changes, less snow or ice is required for site leveling. Site preparation could employ mulching units to grind stumps after clearing of timber and use the mulch to fill in small depressions and micro-relief, which can be followed by icing in or packing snow to smooth the surface and eliminate tripping or tire puncture hazards. The lease need not be completely leveled using ice and snow, but the capabilities of the rig to level itself can be made use of for the final placement of the rig. Taking advantage of the capabilities of drilling rigs to operate on non-level ground could eliminate stripped-soil construction on all but the most severe topography, thereby reducing the intensity of most of the delineation program footprint. Furthermore, combining technologies such as self-leveling rigs and snowmaking equipment should be able to address even severe topographical issues while maintaining safe operating conditions. At the very least, the partial lease stripping practices described in section 4.3 above could and should be eliminated.

Low disturbance wellsite construction should be practiced as commonly on uplands as it is on adjacent lowlands given the improved footprint outcome and the potential savings in construction and reclamation costs. However, the opposite is presently true despite awareness of technology and practices available. One reason may be that despite its existence, suitable equipment is not in abundant supply and is not available for widespread use. Supply of appropriate equipment will not be made available unless it is demanded, which requires leadership to generate the demand. Such leadership could come from the regulator, which would then impose its demands on industry. Ideally, such leadership should come from industry, which is more capable of implementing innovation and leading environmental stewardship. Industry's commitment to land stewardship would also be demonstrated by developing a more comprehensive vision regarding reclamation outcomes as mentioned in section 4.5 above and illustrated in section 7.3 below. Awareness within industry exists of wide ranging possibilities regarding low disturbance practices. Building drilling pads on British Columbia mountain slopes entirely of artificial snow is one example (Dan Hommy, Nexen, Inc., personal communication). However, few of these practices seem to be presently employed in boreal Alberta.

5.2. Pre-disturbance Assessment and Prescription Planning

Some companies collect pre-disturbance environmental information from OSE sites while others do not. Such information is valuable for post-reclamation comparative purposes, but could be even more valuable for prescriptive purposes. For example, knowing the depth of the water table in combination with soil texture information could help predict how susceptible a site might be to post-reclamation domination by marsh reed grass, thereby enabling prescription of preventative measures such as minimizing mulch loads. Pre-disturbance information could also be used for construction planning by identifying which sites might require snowmaking or self-leveling rigs, or for making soil salvage and planting prescriptions on sites where soil stripping is unavoidable. Finally such information could also be used for strategic location of drilling locations so as to avoid sites likely to require soil disturbance (see section 7.2). Basic information collected from sites prior to disturbance for construction and reclamation planning should include the following as a minimum:

- identification and depth of surface layers
- depth to major root zone
- major root zone thickness
- depth to mottles or gley
- texture of soil horizons
- slope steepness and direction
- complexity of slopes
- surface drainage mapping
- canopy composition
- dominant shrub and herbaceous plants

Acquiring knowledge of site characteristics and planning construction and reclamation well ahead of the physical work will enable prescription with site-adapted application of construction and reclamation practices as well as inform final outcome expectations. Equipped with clearer reclamation outcome expectations and developed plans to achieve them, improved results are sure to be achieved.

5.3 Slash and Mulch Management

5.3.1 Slash or Mulch?

While excesses of either slash or mulch can be detrimental to natural forest regeneration, leaving woody debris whole is preferable to mulching it because of potentially reduced soil surface coverage. The criss-crossing nature of whole tree limbs and tops when strewn randomly over the surface of a lease enables it to be piled without covering the entire soil surface. Chipped logs yield a greater volume of material than whole logs that more uniformly and completely covers the soil surface. However, a minimal amount of mulch that does not form a uniform blanket over the site is acceptable.

Mulching as a method to clear a low disturbance site of non-merchantable timber is acceptable provided that the volume of mulch produced is minimal as mentioned above. The maximum depth of mulch covering the lease should not exceed 10 cm. Depths greater than this will impede tree suckering by keeping the soil cool and retaining moisture. Deep mulch can also promote establishment of undesirable herbaceous vegetation such as marsh reed grass. This is particularly true when the water table is relatively high (Fig. 4.2). Pre-disturbance site assessments should note depth to water table or depth to gleying or mottling so that sites at risk of becoming dominated by marsh reed grass can be identified and excessive mulching can be avoided. Mulching should be minimized or avoided where the depth to gley or mottles is 30 cm or less.

Mulching on sites with merchantable or semi-merchantable timber should be restricted to the grinding of stumps to facilitate leveling of microtopography or filling in topographic lows on low disturbance sites. The remaining slash should be left whole as much as possible. Some mulch is beneficial to assist in site leveling, but again, the final volume must not exceed an amount that will produce a mulch layer deeper than 10 cm after final reclamation. An alternative to mulching stumps on low disturbance sites is to pluck them out with a hoe equipped with a thumb attachment (Fig. 5.2).

Fig. 5.2. Trackhoe with thumb attachment. (Photo: Terry Osko)

Mulching slash after timber salvage or to clear smaller woody vegetation is not recommended on stripped-soil sites because of the problem of mixing of wood chips with the soil during the reclamation process as discussed in section 4.1 above. Even the volume of mulch expected to produce a 10cm layer of mulch on the surface is far too much if there is risk of mixing with the soil. Mulching should be avoided on any stripped-soil sites with more than light volumes of slash.

5.3.2 Excess Slash and Mulch

Lieffers and Van Rees (2000) classified slash loads of <200 t/ha, 200 – 400 t/ha, and >400 t/ha as light, moderate, and heavy, respectively. Slash loads of greater than 400 t/ha will moderately to severely affect aspen suckering. Therefore, slash remaining onsite after final reclamation should be less than 400 t/ha. A visual guide is provided in the Appendix to illustrate how the various slash loads would appear on a site.

The amount of slash can be managed by burning excess slash if necessary. However, restraint should be exercised to prevent too little slash from remaining (Fig. 5.3). Moderate levels of slash have a minimal affect on aspen suckering (Lieffers and Van Rees, 2000, Leiffers-Pritchard 2005) but can positively contribute to long-term soil nutrient status as well as provide microhabitat for both flora and fauna. Therefore the goal of burning of slash should not be to minimize the amount of slash present, but merely to reduce the volume to an acceptable (moderate) level when necessary.

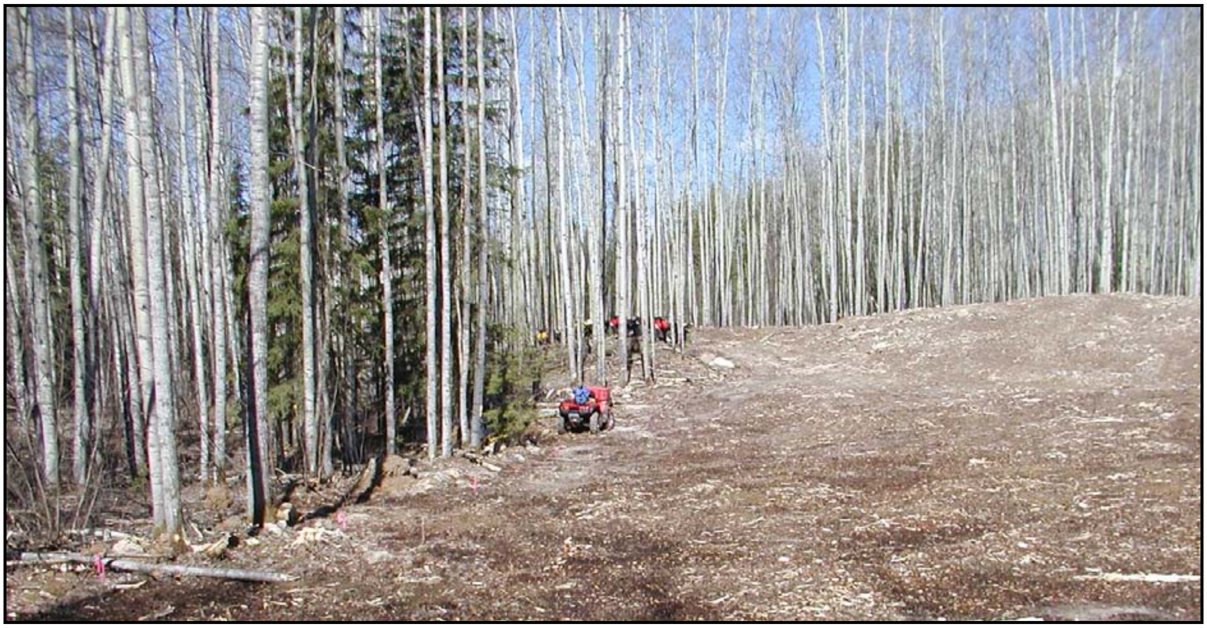
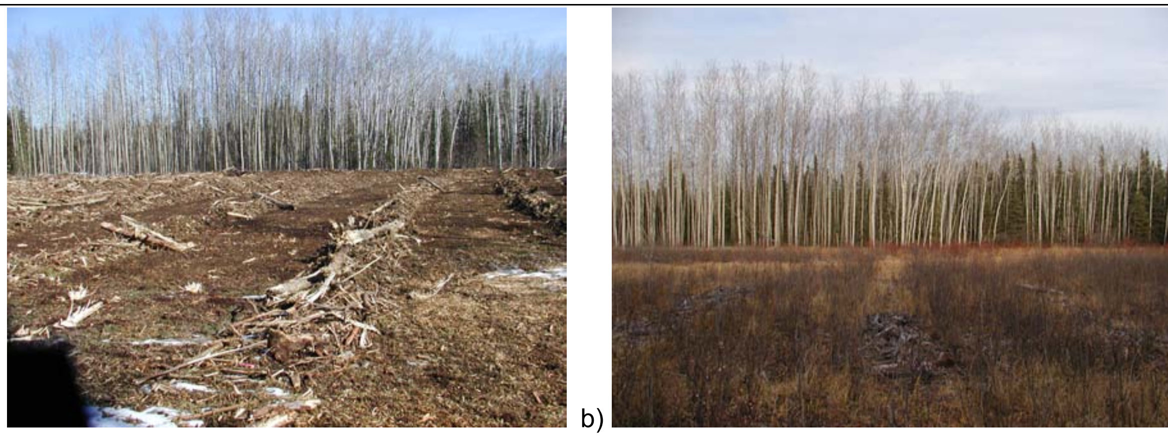


Fig. 5.3. Stripped-soil OSE with less slash on site than expected based on surrounding timber as a result of excessive burning of slash. (photo: Terry Osko)

An alternative to burning that can be effective for both slash and mulch is to pile the material into windrows (Fig. 5.4a), leaving cleared areas of exposed forest floor in between. Soil in the exposed spaces between windrows is not insulated by a layer of mulch or slash and can therefore warm up with the spring thaw to initiate aspen suckering, while the slash or mulch within the windrows decays over time (Fig. 5.4b). Operators should strive to completely expose the forest floor between windrows without removing the LFH or duff layer. Trying to retain a small amount of mulch between windrows runs the risk of leaving too much. In the case of mulch, too much is always worse than too little.



a) b)

Fig. 5.4. An iced-in constructed OSE wellsite with excess slash piled into windrows: a) shortly after reclamation; b) several years later with aspen suckers growing ubiquitously in the inter-windrow spaces. (photos: a) Harvey Harriott, b) Terry Osko)

Windrowing is not generally recommended on stripped-soil sites because it is difficult to pile the windrows without pushing all the surface organic material in to the windrow also, thereby leaving a bare mineral soil devoid of organic input. However, windrowing of slash can be accomplished on stripped-soil sites if a rake is used instead of a blade (Fig. 5.5). As mulch can be a useful material for smoothing the surface of low disturbance drilling locations, a final option for handling excess mulch might be to salvage it from sites where it is excessive and use it as construction material on sites where it is needed.

Fig. 5.5. Rake replacement for traditional blade. (photo: Terry Osko)

If the slash load on a stripped-soil site is determined to be too high after reclamation is complete, the best option is to pile some of the excess with either a rake attachment on a dozer or with a hoe equipped with a thumb attachment and burn the excess. This should be done in frozen conditions either in the same winter as reclamation or returning the following winter. Mulching the excess material in place is not recommended because the volume of mulch will produce a more complete blanket than the whole slash. In addition, as expressed in section 3.7, we observed that mulching of slash after surface soil and slash replacement reduced growth of planted trees and severely impeded natural regrowth of shrubs. Another practice to avoid is attempting to break up some of the excess slash, or push it into the soil, by driving over the surface repeatedly with a dozer in soft conditions (Fig. 5.6). This practice causes rutting of the soil, increases admixing of soil, and also mixes woody debris with the soil, thereby reducing its suitability as a planting medium as discussed previously.

Fig. 5.6 An attempt to manage excess slash by breaking it up with a dozer and pushing it into the soil by driving over it repeatedly with a dozer. Besides causing soil ruts and destroying soil structure, the resultant mixing of soil and woody debris produces an extremely poor tree-planting medium. (photo: Terry Osko)

5.4 Soil Stripping, Storage, and Replacement

In general, the operational plan should be to avoid soil stripping as much as possible as indicated in section 5.1 above. However, if soil stripping is necessary, operators should strive to collect the major root zone together with a substantial amount of soil in a single pass so as to avoid damage to the roots by equipment traffic and scraping with dozer blades. Knowledge obtained from a pre-disturbance site assessment that includes a description of the depth and thickness of the root zone can be applied here. The quantity of soil collected with the root zone should be sufficient to bury most roots in the spoil pile and reduce exposure of the roots to the elements. Surface layers, including woody debris, root zone, and upper sub-soils should be stored in separate spoil piles to avoid mixing of these layers. Excessive mixing of the surface layers can influence the soil tilth, or suitability for supporting seedling growth. Replacement of surface layers from a single pile results in a greater amount of woody debris mixed into the mineral soil layer, tending to form an undesirable mix where naturally occurring tree seedlings would be exposed to greater risks of drought and dislodgement from the soil. While the practice of placing strippings in a single pile may be attractive due to efficient use of lease space, it is not recommended because of the negative effects on both naturally recurring and planted trees.

The surface layers should be replaced equitably over the site; not necessarily evenly and certainly not smoothed, but at a more or less equal depth over the site. Surface roughness is desirable to provide microsites for plant establishment and protection from elements. Ideally, this is best achieved by returning the surface soil (including embedded roots) and the woody debris with a hoe rather than with a dozer. Doing so prevents damage to any live roots, spreads the soil in an equitable manner (especially on complex slopes) without excessive mixing with snow that can lead to misinterpretation of replacement depth, and produces a rougher surface more conducive to establishment by a wider variety of plant species.

5.5 Tree Planting

Herbaceous vegetation can quickly colonize stripped-soil sites, thereby stabilizing the soil and protecting it from erosion. However, natural re-colonization by trees and shrubs is impeded by the lack of viable sprouting roots, the burying of seeds during the construction and reclamation process, and by competition with herbaceous vegetation that quickly establishes. Planting during the first growing season can ensure that seedlings will establish before herbaceous vegetation becomes too competitive. It is possible to delay planting until the second growing season on better-drained sites, as herbaceous competition may be slower in asserting itself, but it is safest to plan for planting during the first season. Again, an effective pre-disturbance assessment program could identify sites where rapid grass establishment may be a concern. Herbaceous vegetation will dominate the site soon enough, but establishing the tree seedlings early will enable them to compete better until they establish dominance over the herbaceous canopy. Seedling species selection should be determined by suitability to individual sites based on the pre-disturbance site assessments. All species we used in our study performed reasonably well on all site types, but a prescriptive approach based on local site conditions and surrounding forest canopy as determined from the pre-disturbance assessments would be more appropriate. In addition, planted trees should originate from seed or vegetative material collected in the seed zone where the site to be planted is located. In the interest of maintaining a productive landbase, forest companies holding the Forest Management Agreement for the area an energy company is operating in are likely to assist in developing prescriptions and sourcing planting material for extensive drilling programs. Fertilizing the soil is not recommended because the fertilizer will benefit competing vegetation as much or more as the planted trees. Since management of competing vegetation is neither recommended nor practical, there is no net benefit to the planted trees by adding fertilizer.

Both poplar and aspen are pioneer species, therefore either could potentially make good candidates for planting. However, the robust growth of poplar makes it preferable over aspen because it is immediately more competitive with the naturally regenerating herbaceous vegetation. Furthermore, planting of rooted poplar cuttings would improve the survival of poplar plantings, thereby giving an even greater advantage to planted poplars. Birch also performed well in a wide range of conditions and is therefore a reasonable choice for a variety of applications. Nevertheless, tree species should be planted in mixes based on a prescription derived from the initial site information or pre-disturbance site assessment. Pine is also a good candidate, but again, used according to prescriptions based on initial site information and not as a generally applied species.

6.0 Clay Pads Left in Place on Wetland Locations

Leaving a clay pad in place on a wetland (peatland) location without returning it to a wetland community constitutes a change in land use, whereby the site will be required to meet the forested land use criteria for reclamation (ASRD 2007). These criteria require that the site be vegetated with both herbaceous and woody vegetation, preferably both trees and shrubs, and that their distribution across the site be relatively uniform. A minor component of our study included some site preparation and tree-planting trials on recently constructed clay pads left in place within a treed poor fen environment. The recommendations from the results of these trials are summarized in this section.

While it is possible for clay pads left in place to eventually revegetate naturally with desirable species, the time required will likely be too long to reasonably wait for a reclamation certificate. Or, if the site is not sufficiently remote, it may be highly susceptible to invasion by undesirable plant species. Therefore, if a site is to receive a reclamation certificate in a reasonable amount of time it will need to be planted with desirable species, including trees and shrubs. Specific planting strategies will depend on the location of the pads, the level of human activity expected within the local area, and the surrounding landscape. Below are recommendations for planting strategies, species selection, and some site prep treatments. The recommendations can also apply to the borrow areas from which the clay for the pads originated.

6.1 Planting Strategies

6.1.1 Sites Exposed to Human Activities (roads, industrial sites, etc.)

Sites located near roads or areas subject to considerable human activity are at higher risk of invasion by weeds or otherwise undesirable plant species. Therefore, unless the intent is to tend the planted trees as one would maintain a commercial plantation, planting the barren clay solely with trees and/or shrubs is not recommended. In addition to planting trees and shrubs, a mix of native herbaceous species suitable to the site should also be planted to reduce the available space for undesirable species invasion. The seed mix should not be applied at an excessive rate, however. Three to four kilograms per hectare is plenty. The light rate will prevent the seeded herbaceous plants from competing too severely with the trees, yet help prevent some of the inevitable weed invasion. While weeds will likely invade the site eventually, the seeded plants will provide competition for them and the eventual tree canopy will cause the weeds to diminish. Trees should be planted at a rate of about 3000 trees/ha with an expected growing stand of about 2000 trees/ha. Logistically, it might make most sense to seed the herbaceous plants first and follow immediately with tree planting.

6.1.2 Remote Sites

Sites that are fairly well protected from human activity and are not in areas surrounded by a significant source of weeds might be safe to plant solely with woody species and allow herbaceous colonization to occur from local seed rain. However, the caution is that a source of desirable seed rain is nearby. It should also be noted that such colonization may take considerable time and that undesirable plants may establish in the meantime. The more remote and isolated from human activity the site is, the less likely it is to be invaded by weeds. However, it may be safer overall to plant a desired mix of herbaceous species to reduce weed invasion.

6.2 Species Selection

Ideally, species to be planted on clay pads left in place should be selected based on the capabilities or condition of the site, combined with a goal to initiate a successional trajectory towards a specific desired plant community. Target plant communities should be compatible with the surrounding landscape and not introduce elements that previously did not exist so as not to unduly affect other ecological factors. For example, introducing deciduous browse species such as poplar or willows to an area previously devoid of them may attract wolf prey species such as moose to areas previously less frequented by them. This increases the risk of incidental predation of threatened caribou herds by wolves should wolves follow moose into such areas (James 1999, James et al. 2004). Resources such as the Field Guide to Ecosites of Northern Alberta (Beckingham and Archibald, 1996) or Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region (Oil Sands Vegetation Reclamation Committee, 1998) can be used to select potential target communities, which in turn can drive species selection. Unfortunately, while most tree species are readily available commercially many species of shrubs and herbaceous plants are more difficult to obtain, thereby limiting the choices available. Alternatives to purchasing commercial seed include transplanting live plants from nearby plant communities, provided sensitive areas or rare species are not disturbed, or collecting seeds of desired plants and have them grown by a commercial nursery for either transplanting or seed propagation.

6.2.1 Trees

Species selection should be based on compatibility with the surrounding area. Obviously, if the site is constructed from borrowed clay fill, the immediately surrounding area will not be upland. However, there may be upland areas in the vicinity that can be used for reference. We tested 4 species for planting on borrowed clay pads: white spruce, jackpine, paper birch, and balsam poplar. Of these, pine was the most successful in terms of survival, followed by spruce. While survival of birch and poplar were lower, these species grew taller more quickly, thereby enabling them to sooner form a canopy and compete better with invading grassy and weedy vegetation. Any of these species would make good candidates for planting. Black spruce is also commercially available and is probably a good candidate for planting on clay pads, given the likely proximity to peatland habitats. Mixed plantings of several species are recommended to increase the resilience of established vegetation to possible future changes in climate or site conditions, as well as to better blend with surrounding vegetation. Ratios will depend on the desired plant community to be established and blending with the surrounding landscape, being especially mindful of eventual effects on broader ecosystem factors, especially caribou. If conifers dominate the uplands in the surrounding landscape, then tree selection should be restricted to use of pine and the two spruce species, using black spruce near the site margins. On the other hand, if deciduous trees are plentiful, then poplar and birch can be incorporated into the site, keeping in mind that poplars will eventually sucker and thereby possibly increase in density over other species.

6.2.2 Shrubs

Shrubs are not as commonly available commercially for operational planting as are trees, but a number of species can be obtained commercially. These include green and river alder (*Alnus crispa, A.* tenuifolia), saskatoon (*Amelanchier alnifolia*), red osier dogwood (*Cornus stolonifera*), choke cherry

(*Prunus virginiana*), prickly and common wild rose (*Rosa acicularis, R. woodsii*), raspberry, Canadian buffalo berry (*Shepherdia canadensis*), and snowberry (*Symphoricarpos albus*). Species selection for site-specific purposes should be directed by key species identified from descriptions of the target community that is to be emulated and can be limited to those few species. Again, it is essential to ensure that the target community will remain compatible with the broader ecosystem and not influence additional ecological factors such as local predator-prey systems. In the absence of commercial availability, shrub selection and acquisition will likely depend on availability from the immediately local area for transplantation. Probably the least labour intensive and efficient option would be to collect willow cuttings locally and plant them onto the site. Cuttings can be collected any time during the dormant season and can either be planted immediately after collection in the fall just prior to freeze-up or in the spring before bud burst. Alternatively, they can be stored frozen over winter for planting the following spring. In either case, it is best to soak the cuttings for a day or two prior to planting (Dave Polster, Polster Environmental Services Ltd., pers. comm.). The density of shrub planting depends on the desired community to be established. About 1000 plants/ha should be sufficient if trees are planted at 3000 trees/ha.

Poplars can also be planted as unrooted cuttings but keep in mind that the survival will be lower than cuttings that have been rooted previously by a nursery. Best results will be achieved if cuttings of either willow or poplar are planted earlier in the spring when soil is moist. Cuttings also require good contact with the soil. The soil surface should be loosened on extremely compacted soils to facilitate good soil contact.

6.2.3 Herbaceous Plants

Herbaceous species selection is probably less critical provided healthy tree and shrub canopies are established. Native species should be selected as much as possible given the constraints of seed availability. In selecting native species, “native to Alberta” is not native enough. There is no point in planting a species that will dominate the site but does not naturally exist anywhere nearby in the landscape. On the other hand, even non-native species can be acceptable provided they too do not dominate the site, do not invade adjacent undisturbed areas, and are likely to become reduced in abundance as the forest establishes. This strategy is consistent with the ASRD guidelines to reclamation of wellsites on forested lands (ASRD 2007), but care must be taken in species selection. While native species are most desirable, the primary focus should be the ecological function or role the herbaceous layer will perform on site. Key functions are to contribute to nutrient cycling on the site, discourage invasion by undesirable or weedy species, and to not compete too severely with planted trees or shrubs. A light planting is essential to achieving the last objective. While establishing a locally native plant community is preferred, non-native species can adequately accomplish this role if non-aggressive species are selected. Once the tree canopy is established, local shade-tolerant plants will likely establish and compete well against the non-native planted species. The species mix should include a nitrogen fixer or two such as a native or non-native legume. Preferred grasses will have a bunched growth form rather than creeping roots. Commercially available native grasses include slender wheatgrass (*Agropyron trachycaulum*), bearded wheatgrass (*Agropyron subsecundum*), hairy wildrye (*Elymus innovatus*), and tufted hair grass (*Deschampsia caespitosa*). Tickle grass (*Agrostis scabra*) will commonly establish on its own on disturbed sites (Hardy BBT Ltd., 1989). Red fescue is an acceptable non-native species provided the non-creeping variety (*Festuca rubra var. commutata*) is used. Creeping red fescue will form a sod that is more competitive with trees and can prevent the natural establishment of native species. Commercially available native forbs include fireweed (*Epilobium angustifolium*), pea vine (*Lathyrus ochroleucus*), and American vetch (*Vicia americana*). Alsike clover (*Trifolium hybridum*) is an acceptable non-native legume.

6.3 Site Preparation

6.3.1 De-compaction

Soil compaction is inherent in the process of constructing a pad from borrowed clay fill. Therefore, some form of de-compaction would presumably be beneficial prior to planting trees onsite. We observed that disking the soil surface with a breaking disk (Fig. 6.1) improved overall survival of planted trees, but pine survival was high regardless of whether sites were disked or not. Disking also improved tree growth. Both heights and diameters of trees were greater after 5 growing seasons in response to disking. However, poplar and pine tended to have less marked responses than birch and spruce. Ripping the subsoil prior to disking the surface appeared to be of mixed benefit. Ripping improved the growth of birch over disking alone, but ripping was either detrimental or had no effect over and above disking for other species. Ripping also had mixed effects on seedling survival, having a negative effect on spruce survival but only having marginal effects on birch and pine survival. Therefore, disking the soil is apparently sufficient preparation for planting, while ripping in addition to disking achieves little additional benefit. As a caveat however, our observations were made on a limited number of replicates and common sense would indicate that loosening the sub-surface should be beneficial, especially on older sites. It is likely that any attempt at loosening the soil surface prior to planting will be beneficial, whether it is ripping, disking, or even mounding as is regularly practiced in forestry. However, applying both treatments is unnecessary on relatively recently constructed clay pads. A looser planting medium produced by any method is desired if poplar or willow cuttings are to be planted so that good soil contact with the cutting is ensured.

Fig. 6.1. Disking to loosen soil surface on clay pad constructed for an observation well related to a Steam Assisted Gravity Drainage pilot. In this case, salvaged peat was also incorporated into the soil with the disk. (photo: Barb Thomas)

6.3.2 Soil Amendments

Borrowed clay material will inherently be nutrient poor, marked by absence of organic material, implying that planted trees will benefit from some form of fertilizer application or soil amendment. On the other hand, if clay pads are susceptible to invasion by weeds or other undesirable plants, fertilization will also increase the competitiveness of these plants. Intensively managed plantations benefit from fertilization, increasing wood production from 3 to 10 m^3/ha over periods of 5 years or more (Fisher and Binkley, 2000). However, when understory competition is not controlled, adding fertilizer can result in almost a tripling of understory biomass with little if any benefit to the planted trees (Fisher and Binkley, 2000). Therefore, fertilization is not recommended if the planted trees are not to be intensively tended.

We evaluated the effects of adding salvaged peat from a treed poor fen as a soil amendment on the survival and growth of planted poplar, pine, birch and white spruce over 5 years. Survival of birch and poplar was negatively affected by the peat amendment but pine and spruce showed no response. Poplar and birch growth was also reduced, but pine growth increased slightly. Soil pH was higher on the peat-amended soil but was still within acceptable ranges (pH 7.7 vs. 7.3). Organic carbon was also higher on peat-amended sites with no apparent effect on carbon:nitrogen ratio, which presumably would favour growth on the peat-treated sites. The negative results are therefore curious. Abu-Hamdeh et al (2000) observed that thermal conductivity was reduced on disturbed soils amended with peat. Perhaps the peat prevented amended soils from warming sufficiently and thereby interfered with tree performance. Furthermore, water retention and soil moisture appear to be increased on peat-amended soils (Li et al 2004, Vepsalainen et al 2004). Increasing water retention on structureless clay soils that already tend to retain moisture may contribute to additional soil cooling and extension of saturated periods, thereby adversely affecting growth of some tree species. Another potential effect of peat amendment is reduced microbial activity. McMillan et al (2007) observed that microbial activity and soil respiration rates were higher on reclaimed oil sands mine soils amended with forest LFH layer material than those amended with peat. Vestberg et al (2009) reported peat amendment reduced microbial biomass and reduced mycorrhizal effectiveness. It is unknown whether responses to fen peat or *Sphagnum* peat would differ. Given the cost of transportation and lack of apparent benefit, application of peat is not generally recommended, particularly if birch or poplar are to be planted. However, more study may be required. Peat application may be of benefit to sites where conifers are to be planted if a supply of peat is nearby and it can be applied at low cost.

Where woody debris has been salvaged from a borrow area prior to excavation, these materials and any salvaged surface soil should be replaced over the borrow area upon decommissioning. There is no benefit to mulching the woody debris. Growth of planted pine, birch, and poplar was reduced on sites where salvaged woody debris spread over a former borrow pit was mulched in place.

7.0 Planning and Operational Recommendations

7.1 Exploring Footprint Reduction Opportunities

The previous sections dealt primarily with reducing footprint intensity, but reducing the industrial footprint can also be achieved by footprint avoidance, namely by avoiding the need to construct features in the first place or to minimize the size of the features constructed. While we did not examine footprint avoidance directly in our study, it represents a great opportunity for removing the wellsite footprint. Some suggestions for footprint avoidance are introduced below.

In situ oil sands exploration involves the drilling of hundreds of exploration wells by each company every winter. Given uniform spacing with a saturation level of at least 16 wells per section, the horizontal distance between wells would be, on average, not more than 400 m. Spacing can often be much closer, especially at higher saturation densities. An obvious opportunity for footprint avoidance is drilling of several OSE wells by angle drilling from a single pad location, thereby reducing the number of surface disturbances required and enabling strategic positioning of surface locations to avoid areas requiring substantial surface disturbance.

At an average saturation density of wells and equal spacing, target locations would be less than 283 m horizontal distance from a centrally situated top-hole location (the short side of a right triangle with the surface location centred between the vertical projection of four bottom-hole locations 400 m apart, see Fig 7.1). Such a distance would not be a challenge using today's directional drilling technology, despite the shallow depth to which many OSE wells are drilled. At the spacing described above, depths as shallow as 300 m could be reached based on a maximum drilling angle of 45°. Deeper targets would reduce the drilling angle required or allow for reaching targets at greater horizontal distance from the top-hole location. Drilling of 4 or 5 wells from a single location could reduce the surface footprint by at least 75%, reducing to one quarter the surface locations, access road development, and final reclamation required. Furthermore, drilling locations could be selected strategically, selecting for sites that require less surface disturbance for pad and lease construction, thereby reducing costs of construction, intensity of disturbance, and subsequent reclamation efforts (Fig 7.2).

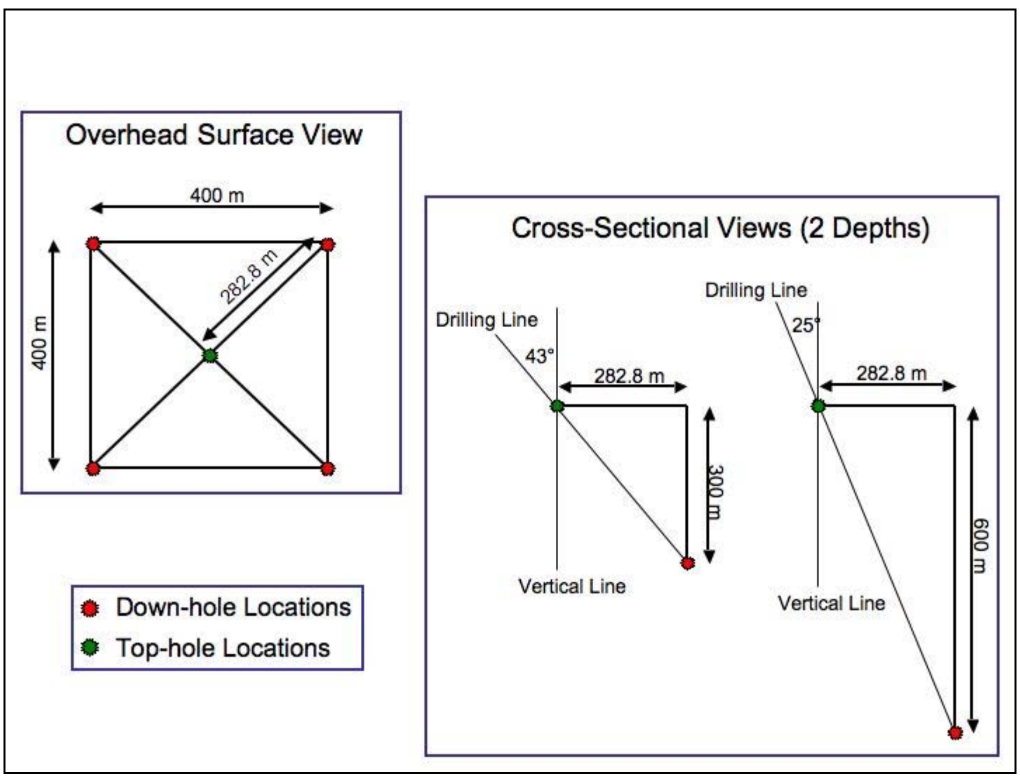


Fig. 7.1. Overhead and cross-sectional views of hypothetical slant drilling geometries assuming OSE well saturation density of 16 wells per section and average spacing of 400 m. Depths as shallow as 300 m can be reached while remaining within the 45° drilling angle limit of slant drills. Deeper wells are easily accommodated due to a more vertical drilling angle.

Fig. 7.2. An OSE located near the edge of a small upland ridge within a predominantly lowland area. The lease was constructed by transferring the upslope mineral material down slope to produce a level pad and then moving the material back upslope upon abandonment. The result is a disturbed upslope position and a buried down slope position due to incomplete removal of transferred materials. Moving the well centre approximately 40 m to a level location would have reduced construction costs and footprint intensity by eliminating the need for any soil disturbance at all. (photos: Terry Osko)

Resistance to drilling multiple OSE wells from a single pad arises from objections based on cost, equipment availability, and quality of data obtained. Using directional drilling tools does add cost. Several drilling contractors stated that directional drilling would add $10,000 to $20,000 to the daily drilling costs as compared to vertical holes. Furthermore, directional drilling requires a competent sub-surface formation that will not collapse (Jim Hamilton, Engineering Mgr., Precision Drilling, pers. comm.). These typically occur at deeper depths. On the other hand, angle drilling can be achieved without directional tools. Rod Schmidt of Treo Drilling Services Partnership indicated that coring could be accomplished by drilling at an angle without directional tools to target depths up to 600 m with no added costs and no need to increase lease clearing size. The majority of holes drilled for the Nexen's Long Lake project and ConocoPhillips' Surmont project are within this depth range. In addition, slant drilling could be used on targets as shallow as 100 m (Don Golddale, Ops. Mgr., Trailblazer and Akuna Drilling, pers. comm.).

According to Nexen and ConocoPhillips construction representatives, stripped-soil sites cost between $10,000 and $30,000 depending on the amount of soil to be moved to construct. Therefore, a drilling program of 200 upland wells over a winter represents a potential cost savings of $1.5M to $4.5M in reduced lease construction and reclamation alone if multiple OSE wells were drilled from a single location. Additional savings of $2000 to $6000 per lease would be accrued in reduced construction supervision and camp costs, further reducing the annual drilling budget by up to $1.2M. Savings would also be realized in reduced mobilization costs. Even if the cost of each drilling location were a bit higher should extra lease space be required or should angle drilling be more expensive, the savings in reduced drilling locations should offset any increased costs per location. Moreover, the benefits of reduced disturbance area and intensity through strategic site selection would contribute greatly to footprint reduction. Finally, drilling multiple delineation wells from a single location might enable achievement of saturation more quickly, thereby producing the required geologic information sooner than by drilling conventional vertical core holes.

Slant drilling rigs are not as common as vertical rigs and may not always be readily available. However, as discussed in section 5.1, demand for such equipment will encourage production of a supply. The time would likely be relatively short for drilling contractors to re-tool with slant drilling equipment if resource developers made it clear that is what they require.

Data quality is likely the most problematic issue, since effective extraction of the petroleum resource depends on accurate predictions of where it lies under the ground surface. The pattern of OSE wells drilled reflects iterative spatial statistical routines that indicate where the next well should be drilled based on the locations of previously drilled wells. This does not always lend itself to a predictably systematic layout of well locations. Nevertheless, while acquisition of optimal geologic information likely saves money by improving extraction of the petroleum resource, the footprint resulting from this acquisition has increased environmental costs. Obviously there is a trade-off. A sensitivity analysis that quantified the data quality loss associated with various alternative drilling scenarios would be beneficial to determining whether an exploration program with a smaller footprint was achievable and whether reduced costs in producing that footprint might sufficiently offset losses resulting from sub-optimal data. For example, if it is likely that additional OSE wells will be drilled in the vicinity of initial wells, perhaps well clusters drilled from centralized locations could eliminate the need to return to a vicinity in future years to drill new wells within a few hundred metres of previously drilled wells. Thus, additional costs and additional surface disturbance could possibly be eliminated while only marginally affecting resource delineation predictions.

Another opportunity for footprint reduction is to clear a smaller area for the operation of the drilling rig. Many in situ oil sands developers use a standard 70 m x 70 m lease clearing, while others have accommodated smaller clearings in their delineation programs. Generally speaking, the clearing size required depends on the size of the rig required, which in turn depends on the depth of delineation well to be drilled (Rod Schmidt, VP Operations, Treo Drilling Services Partnership, pers. comm.). Rigs drilling to 300m or less can operate on a cleared space of 30 m x 30 m. Rigs drilling to 1000 m will require a space of 40 m x 40 m, but 50 m x 50 m is preferred. Rigs drilling to 1500 m will need a larger lease again. Other factors influencing lease clearing size are whether or not blowout protection (BOP) is required, the amount of associated equipment or buildings needed, space required to store salvaged woody debris and soil strippings, and logistical space to ensure trucks can deliver equipment and buildings. These factors can dictate a larger clearing despite the ability of a rig to operate on less space. A potential option for reducing overall lease size might be to explore alternate lease geometries that could accommodate the spacing requirements. For example, larger leases are needed to accommodate minimum distances to flares if BOP is required. If flaring waivers cannot be obtained, perhaps extending one corner of a smaller lease rather than increasing the length of each side of the lease could achieve the desired flaring distance. Another option for reducing lease clearing size for OSE exploration, given that numerous wells will be drilled within a relatively concentrated area, is to eliminate the drilling shack from each drilling site and have it located in a central location. Similar options are to use a smaller self-propelled shack arrangement such as a modified van, or use of a collapsible unit that can be transported by helicopter or smaller ground equipment.

7.2 Integrated Planning

While the main priority of resource developers is obviously to develop the resource, this by no means precludes integration of other priorities such as environmental footprint reduction into their operations. Such integration requires that a clear vision of what a company hopes to accomplish in terms of footprint outcome be integrated into planning of the development operations. Furthermore, this vision should be based on what is achievable in terms of best practice, as opposed to expectations required by the environmental regulator at a given time. Once established, analysis of how this vision can be implemented must then be undertaken in collaboration with affected departments or operations within the company. Consultation or negotiation with respective government agencies may also be required. Finally the vision must be communicated and put into effect at all levels of the development process.

A potential scenario based on the recommendations included in this document follows below. The scenario is likely not much different than processes presently in place with most companies except for the integration of footprint reduction at a greater number of decision making levels. A company sets the following goals: 1) to reduce the number of OSE well locations in its delineation program; 2) position as many OSE wells as possible in low disturbance/low cost locations; and 3) maximize low disturbance construction practices. The first step is to have the geology department complete a sensitivity analysis to determine how many OSE locations can be eliminated without unduly compromising the resource delineation. We will assume a 25% reduction in locations is determined achievable. Next the company negotiates with the Energy Resources Conservation Board to justify the reduction in sampling locations, while preliminary drilling locations are selected. A reconnaissance of the sites is completed by the company’s environment department, which identifies 15 drilling sites that should be relocated based on the surface disturbance that will be required to drill them and suggests alternative locations to geology. Geology accepts 8 of the recommended moves but insists on the retaining the positions of the remaining 7. The sites are then surveyed and pre-disturbance environmental information is collected. Based on the pre-disturbance information, environment, construction, and drilling departments collaborate on construction, drilling, and reclamation prescriptions. Decisions include what type of construction practices or combinations will be employed, such as whether snow-making equipment will be needed or whether the site can be iced-in with hauled water, whether and how much woody debris will be mulched, and how soil will be salvaged and stored. Other decisions will include clearing size, shape, orientation, and whether specialized rig equipment will be used. Sites that will require tree planting or other specialized treatment will be identified and prescriptions developed. The detailed construction and reclamation plan will then be issued to the construction and drilling contractors, who, having been trained with respect to expected outcomes and the practices to achieve them, will be empowered to implement the plan successfully. The contractors’ performance will be audited to ensure compliance to the company’s vision and all steps necessary to ensure quality work will be taken.

The above approach may require more internal communication and collaboration between company departments than presently occurs. In addition, the planning process may have to begin sooner than usual for some departments. And finally, greater collaboration may be required from government regulators. Increased coordination and communication among company departments may represent an increase in initial workload, but ultimately, these efforts should result in enhanced environmental stewardship and savings in construction and reclamation costs. Furthermore, as this process is learned and refined over time, far less effort will be required.

7.3 Communication, Training, and Quality Control

Permeation of the company vision for environmental footprint outcomes throughout business units will require communication and training, much like the development of safety or anti-harassment culture. Environmental culture is likely strong in most companies, but probably not so much with respect to a specific aspect such as footprint reduction. Targeted training programs could be developed for respective business units, with varying emphases for construction contractors as opposed to geologists. However, core messages such as the need to reduce the number and intensity of disturbances and what can be accomplished by doing so should transcend the various business units. An example from forestry is the effort of Alberta-Pacific Forest Industries Inc. (Al-Pac) in developing corporate culture around desirable stand structure remaining in harvested forest cutblocks. The core of the training materials is *An Operator’s Guide to Stand Structure*. Although targeted to harvest operators, the guide presents important environmental concepts and outlines the goals of appropriate stand structure in plain terms easily understandable by most readers. The manual also reinforces the training material with visual guides and examples. The manual is useful as a universal training reference that can be supplemented with additional training if necessary. For example, the manual can be used as stand alone material for employees not directly involved in timber harvest, but need to be familiar with company practices in general terms. On the other hand, timber harvest contractors receive additional training in the field and are regularly audited by harvest coordinators, first to reinforce training received, and later as means of quality control.

Energy companies serious about footprint reduction would benefit from emulating this training strategy. Doing so would standardize operations around specific goals and targets for reclamation outcomes and reduce uncertainty regarding acceptable practices. Standardizing operations through such training would improve footprint outcomes by ensuring appropriate practices are suitably targeted to various applications rather than applying practices universally to all sites with mixed success.

8.0 Conventional Oil and Gas

While much of the research associated with this report was performed on OSE wellsites and a number of the recommendations are framed in the context of in situ oil sands exploration, most of the recommendations can also be applied to conventional oil and gas exploration. Certainly some recommendations such as reducing clearing size by having a centrally located drilling shack may not be practical for conventional oil and gas exploration when drilling sites may be more dispersed both temporally and in space. However, general concepts of reducing clearing size by altering lease geometry, or strategically selecting locations where lower disturbance can be achieved by angle drilling, are equally applicable to OSE and conventional applications. In reality, a disturbed site is a disturbed site regardless of what the purpose of the disturbance was.

It may seem less practical to consider low disturbance methods or to salvage roots on conventional wellsites when, unlike OSE sites, the hope is that the well will be operational and will not be abandoned in a short time. But applying these practices can be practical and environmentally beneficial as well. The low disturbance approaches discussed in this report can be applied to conventional wells regardless of whether a well will produce or not. If a well does not produce, the reclamation process will be easy and cost little. If it does produce, the area required immediately around the wellhead for well operation can be developed after well completion with the remainder of the lease left undisturbed and requiring little attention at time of final reclamation. Similarly, it would be beneficial to salvage roots as described previously on stripped-soil conventional wellsites. If a well does not produce, then the roots and soil can be replaced with a hoe to enhance woody revegetation over the entire site post-abandonment. If the well does produce, as much of the site as possible should be reclaimed with the salvaged material, leaving only as much space as required to operate the well left unreclaimed until final abandonment. Some operators comment that leases with operating wells should be left unreclaimed because there may be need to redisturb the area to service the well. However, final reclamation of the site will take less effort and financial resources if most of it is occupied by natural vegetation promoting soil-building processes despite occasional disturbances.

Other practices discussed from managing woody debris to developing training programs to communicate a company vision can all be applied to conventional petroleum development as well. The goals of conventional oil and gas development should be the same as oil sands development in terms of reducing the associated footprint, and the tools to accomplish them are largely the same. All that is required is adaptation to the specific situation at hand.

9.0 Conclusion

Technology and practices to accomplish footprint avoidance and intensity reduction presently exist and awareness of these is not absent. However, these practices are not always widely or consistently applied. Leadership is necessary to adopt these practices and make them industry standards. Each company operates within its own economic and environmental constraints based on the uniqueness of its management and the physical landscape in which it operates. Thus each company will have to weigh the merits of adopting specific technologies or practices to their operations. Regardless of these individual differences however, all companies could likely benefit financially as well as with respect to their environmental outcomes, by developing a footprint reduction culture as a component of their existing environmental culture. The content of this report provides ideas for initial actions and discussion points for continued action. We sincerely hope that footprint reduction philosophy and strategies will be integrated into many companies' standard operations and that this report will spark discussion within industry and among agencies toward that end.

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Appendix: Visual Guide to Slash Loading on Wellsite

Rationale

Heavy slash loads can reduce soil temperatures, which in turn can negatively affect the numbers and growth of aspen suckers. Early sucker growth is important because it maintains the parental root system, thereby affecting both onsite revegetation potential and offsite tree health and vigour. Maintaining appropriate slash loads that are evenly distributed on recovering wellsites will help to maintain healthy root systems and encourage the growth of fully stocked stands. Whereas too much slash can be detrimental to forest regrowth, light or moderate amounts of slash are beneficial to long-term soil fertility. The appropriate amount of slash can be visually determined in the field using the guidelines in the table and photos below.

Appropriate Slash Loads

	Light	**Moderate**	**Heavy**
Slash Load (t/ha)	<200	200 – 400	>400
Forest Floor Visible (%)	>60	40 – 80	<20
Effects on Tree Regrowth	None	Minimal	Moderate to Severe

Operators should strive to maintain light to moderate slash loads onsite and avoid heavy slash loads. These amounts can be achieved by burning, but care should be taken to avoid burning so much slash that too little is left behind. An alternative to burning is to either windrow or pile the slash with a dozer or hoe. Always use a rake attachment on dozers for windrowing or piling on cut & fill constructed sites to avoid pushing salvaged surface soil into windrows or piles.

Visual Guide

LIGHT SLASH LOAD (<200 t/ha)



MODERATE SLASH LOAD (200 – 400 t/ha)



HEAVY SLASH LOAD (>400 t/ha)



LIGHT SLASH LOAD (<200 t/ha)

MODERATE SLASH LOAD (200 – 400 t/ha)

HEAVY SLASH LOAD (>400 t/ha)

Acknowledgement of Source Material

The data and photos appearing in this appendix were adapted and used with permission from the following documents:

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