Literature review on the Restoration of Alberta's Boreal Wetlands

Affected By Oil, Gas and In Situ Oil Sands Development

Prepared for Ducks Unlimited Canada

January 2009

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Executive Summary

The northern Alberta landscape is rapidly being developed by the oil and gas industry, among others. This landscape is dominated by wetlands (mainly peatlands) which by nature are sensitive to disturbance. Energy sector disturbances include the construction of pipelines, roads and well pads, and cutting seismic lines. The main effects on wetlands caused by these disturbances are 1) fragmentation of the landscape, 2) destruction of habitat, 3) changes to hydrology caused by drainage and compaction, and 4) soil and water contamination from hydrocarbon spills or mineral/clay soils used for construction. The best way to mitigate these effects is through improved management practices and restoration of affected areas which are no longer in use.

Within the last ten years the energy sector has developed best management practices (BMPs) to lessen its impact on wetlands. Seismic lines, for example, have reduced their width from 6 m to 1.7 m. New technologies allow several wells to be placed on the same pad, greatly reducing infrastructure and resulting fragmentation. This literature review outlines a multitude of other BMPs that could greatly reduce the energy sector's impact on these fragile ecosystems. Unfortunately, provincial regulations do not require BMPs to be carried out; this means that stewardship relies on the good-will of oil and gas companies.

Restoring hydrologic function is a critical step in restoring wetland vegetation structure and ecosystem function. Several techniques have been developed for restoring wetland hydrology in eastern Canada and Europe. These techniques can be as simple as blocking drainage ditches or they can be more complicated, such as terracing or creating retention basins. It is not known if such techniques can be transferred to the sub-humid climate of the boreal plain.

If hydrology is restored, wetland vegetation may recolonize disturbed areas naturally. However, if target vegetation does not naturally recolonize restoration sites, plants can be introduced by transferring a donor seed bank, seeding or transplanting plugs or rhizomes.

Wetlands affected by energy sector disturbances have been restored on Alaska's North Slope. These sites were revegetated with fast-growing native species in order to help surrounding vegetation to establish. Researchers found that fertilization was imperative for vegetation establishment on these poor tundra soils. Additionally, they developed techniques for reclaiming soils affected by hydrocarbon spills.

A comprehensive method has been developed for the restoration of cutover peatlands. This six-step method is relatively inexpensive and can be carried out entirely using machinery. Techniques for restoring cutover peatlands should be applicable to energy sector disturbances because of similarities in the effects these disturbances have on peatlands.

Studies on restoring boreal wetland affected by energy sector disturbances have just begun. Although some companies have removed or partially removed well pads, only one company (Imperial Oil Resources) had documentation. Imperial Oil Resources initiated a field trial in 2008, which will be completed in late 2009/early 2010. In this field trial, a well cap will be removed or partially removed and natural succession will hopefully allow surrounding vegetation to recolonize.

Current remediate practices for decommissioned roads and well pads leave the mineral caps intact and revegetate them with upland species. These practices will not restore the ecological function or structure of the wetlands which existed prior to disturbance. Most importantly, these areas will not return to a peat-accumulating ecosystem. In light of global warming we cannot afford to forgo carbon sequestration in these wetlands. Restoring these areas will also greatly reduce the effects of fragmentation.

Table of contents

List of figures

List of tables

List of appendices

1. Introduction

1.1 Purpose

Canada's boreal region is one of the largest in-tact ecosystems on the planet, containing a quarter of the world's frontier forests (Bryant et al. 1997). Wetlands are an important component, making up 30% of the Canadian boreal ecosystem (Canadian Boreal Initiative 2008). In northeastern Alberta, wetlands dominate the landscape. Wetlands make up over 50% of the land base and, of these wetlands, over 90% are peatlands (Vitt et al. 1996). Wetlands provide valuable environmental services such as stabilizing the water cycle, acting as carbon sinks, and providing important habitats for plants and animals. Peatlands are an important element of the global carbon cycle, storing approximately one third of the world's total soil carbon (Gorham 1991; Turunen et al. 2002). Boreal wetlands provide breeding habitat for more than 13 million ducks and waterfowl (Canadian Boreal Initiative 2008).

Oil, gas and in situ oil sands development has greatly impacted northern Alberta's wetlands through the construction of roads, pipelines, seismic lines, power transmission lines and well pads (Turchenek 1990; Forest 2001). For example, a 6,000 km^2 study area in northern Alberta was crossed by 236 gravel roads, 7,111 km of seismic lines and 1,600 well sites (Turetsky & St. Louis 2006). Fragmentation, caused by such a high density of linear disturbances, could seriously undermine the integrity of this ecosystem (Turetsky & St. Louis 2006). While development of the oil sands area is certain, the footprint of these disturbances could be reduced greatly by improved management practices and restoration of these sites after decommissioning.

Historically, the Alberta government did not require decommissioned well sites, roads or pipelines located in wetlands to be restored back to wetlands (Alberta Environment 1995). Presently, the government is trending toward requiring restoration of wetland function, but options remain for reclaiming disturbed wetland sites to other land uses (ASRD 2007, Reclamation Criteria Advisory Group 2008).

Restoring wetlands and the hydrological processes affected by in situ oil sands development will become increasingly imporant in the next decades. Over 80% of the oils sands deposits are deep below the surface and must be extracted using in-situ techniques (Alberta Energy and Utilities Board 2005). If all available in situ resources are mined, the area affected would correspond to 21% of landbase of Alberta and would be fifty times larger than that of the open-pit mined area (see Figure 1) (Schneider & Dyer 2006).

Figure 1. A map of open-pit and in situ oil sands reserves of Alberta (Schneider & Dyer 2006)

The objective of this review is to provide an overview of best management practices and restoration work to mitigate the energy sectors disturbance on boreal wetlands. The focus of this review is restoration that is pertinent to wetlands affected by conventional oil and gas as well as in situ oil sands development. A brief descriptive overview of boreal wetland classifications, wetland distribution in Alberta, peatland hydrology and peatland succession will be given. Then, the following questions will be answered:

- What effect do the major disturbances have on wetlands?
- How sensitive are different wetland types to energy sector disturbances?
- What are the best management practices being carried out by industry in wetland-rich boreal areas?

- What restoration techniques would be pertinent to wetlands disturbed by the energy sector?
- What restoration and/or remediation activities have been carried out on these wetlands?
- What are the current reclamation practices for oil and gas companies?

1.2 Methods

Information for this literature review was acquired from scientific databases, working reports from the oil sands industry, governmental reports and documents from NGOs. Appendix A shows the specific databases searched and keywords used. Over 250 articles were reviewed and more than 100 articles were cited in this document. Three government agencies, four environmental consulting firms and 11 oil and gas companies were contacted for information on restoration/reclamation procedures and research projects. See Appendix B for a detailed list of organizations and people contacted.

2. Background

2.1 Wetland classification and properties

The Canadian Wetland Classification System (CWCS) defines wetlands as areas saturated with water long enough to promote wetland processes, including water logged soils and hydrophytic vegetation (National Wetlands Working Group 1997). Wetland development is mainly controlled by hydrologic, chemical and biotic gradients which are often strongly correlated. Five wetland classes have been identified using these gradients: shallow open waters, swamps, marshes, fens and bogs. The definition and description of wetland classes are based on environmental parameters, such as hydrology and water chemistry (Table 1) as well as characteristic vegetation cover (Table 2). These classes are also used for defining Alberta's wetlands (Alberta Environmental Protection 1997) and informing development of Alberta's wetland policy (Alberta Water Resources Commission 1993).

Table 1: Surface water chemistry in the wetland classes from Elk Island National Park of central Alberta (Nicholson 1995; Zoltai & Vitt 1995).

	Bog	Fen	Swamp	Marsh
pH	3.5-3.6	4.0-6.2	5.6-6.1	5.2-6.4
Electrical conductivity (µS cm^{-1})	16-27	40-160	230-330	160-530
Ca (mg l^{-1})	4-7	2-33	26-43	27-65
Na (mg l^{-1})	2-3	2-5	5-22	3-125
Organic N (µg l^{-1})	2900-3000	1350-2850	2000-3000	200-2500
NO_3^- (µg l^{-1})	13-20	8-23	7-10	9-175
NH_4^+ (µg l^{-1})	160-250	23-80	28-146	73-130
P (total) (µg l^{-1})	350-480	135-400	220-650	250-520

Shallow open waters are non-peat forming wetlands with a water level of less than 2 m in midsummer (National Wetlands Working Group 1997). The chemistry of this wetland class is variable and cannot be used to distinguish it from the other wetlands. The vegetation observed in these wetlands are submerged and floating aquatic plants (Table 2).

Table 2: Characteristic vegetation of the wetland classes (National Wetland Working Group 1997).

Wetland Class	**Characteristic vegetation**
Shallow water	Submerged and floating aquatic plants.
Marsh	Emergent sedges, grasses, rushes and reeds with shrubs or trees on edges and submerged and floating aquatics in open water areas.
Swamp	Deciduous or coniferous trees or shrubs, herbs and some mosses.
Fen	Sedges, grasses, reeds, Sphagnum mosses and brown mosses; sometimes shrubs (willow and bog birch) or a sparse tree layer (Black Spruce and Tamarack).
Bog	Sphagnum mosses, lichens, ericaceous shrubs

Marshes are open, non-peat forming wetlands that are dominated by sedges, grasses, rushes and shrubs (Table 2) (Mitch & Gosselink 2000). They are characterized by seasonal water level fluctuations, high water flow, and are influenced by ground and surface waters. The influx of surface and groundwater creates high concentrations of nitrogen and phosphorus, leading to high vascular plant production. Although production is high, there is little to no peat accumulation due to high decomposition rates.

Swamps are forested, wooded or shrubby non-peat forming wetlands (National Wetlands Working Group 1997). As with marshes, swamps have strong seasonal water level fluctuations and high biomass production. Again, peat accumulation is limited in swamps because decomposition rates are high. Swamps are quite diverse in vegetation and in Alberta may be composed of some combination of *Larix laricina*, *Picea mariana*, *Betula*, and *Salix* (Hasley 2007).

Peatlands, also called muskegs, are defined as fresh-water wetlands which accumulate extensive organic matter or peat (National Wetlands Working Group 1997). Peat is the partially decomposed remains of plants which form where the rate of production exceeds the rate of decomposition (Mitsch & Gosselink 2000). Peatlands are ubiquitous in the cold, wet climates of Northern Europe and North America (Wieder et al. 2006). Fens and bogs are two sub-classes of peatlands and can be differentiated according the amount of peat accumulation, hydrology, pH and plant composition.

Bogs are extremely acidic peatlands with no significant inflow or outflow of groundwater (Table 1). Bogs receive their surface water only from precipitation and are therefore called ombrotrophic (Mitch & Gosselink 2000). The water table is generally 40 to 60 cm below the peat surface. They harbor acidophilic vegetation, such as *Sphagnum* mosses and ericaceous species (Table 2) (Mitch & Gosselink 2000).

Fens are peatlands which receive runoff from surrounding or underlying mineral soils and are, therefore, richer in minerals and less acidic. Fens are dominated by grasses, sedges, reeds and brown mosses (Table 2) (Mitsch & Gosselink 2000). These systems can vary greatly depending on the amount of peat accumulation and, consequently, the amount of groundwater inflow. Vitt (1994) categorized Alberta fens as falling into three basic categories. Poor fens (pH 4.5-5.5) are poor in base cations, have no or little alkalinity, and are dominated by *Sphagnum* mosses and sedges. Moderate-rich fens (pH 5.5-7.0) have low to moderate alkalinity as well as concentration of cations. Extreme-rich fens (pH above 7.0) have high concentrations of base cations and high alkalinity, and possibly marl deposits. Both of the latter fens are characterized by brown mosses, grasses and sedges (Table 2).

2.2 Wetland distribution in Alberta

There are approximately 103,000 km^2 of wetlands in Alberta, which represents 16.3% of the province's land base (Vitt et al. 1996). Most of these occur in the Boreal forest natural region and are peatlands (90.4%) (Figure 2). Wetlands which don't accumulate peat (i.e. swamps and marshes) dominate the Parkland and Grassland Natural Regions (Figure 2).

Climate, specifically mean annual temperature and thermal seasonal aridity TSAI (total annual precipitation/mean growing season temperature) mainly control the distribution and type of wetlands (Vitt et al. 1996). TSAI has also been recognized as the primary factor influencing the southern limit of peatlands (Halsey et al. 1998).

Salts within the substrate also explain wetland variation across the province. Areas with comparable climates have higher amounts of non peat-accumulating wetlands where solonetzic soils are present (Vitt et al. 1996). This might be related to the inability of mosses to establish viable communities in saline conditions (Vitt et al. 1993).

Bedrock geology, substrate texture and topography also influence wetland type and distribution (Halsey et al. 1997). Peat with high hydraulic conductivity supports patterned fens, while non patterned fens and bogs are associated with peat that has a low hydraulic conductivity. Finally, bogs are commonly found on acidic bedrock while fens are found on calcareous bedrock (Halsey et al. 1997).

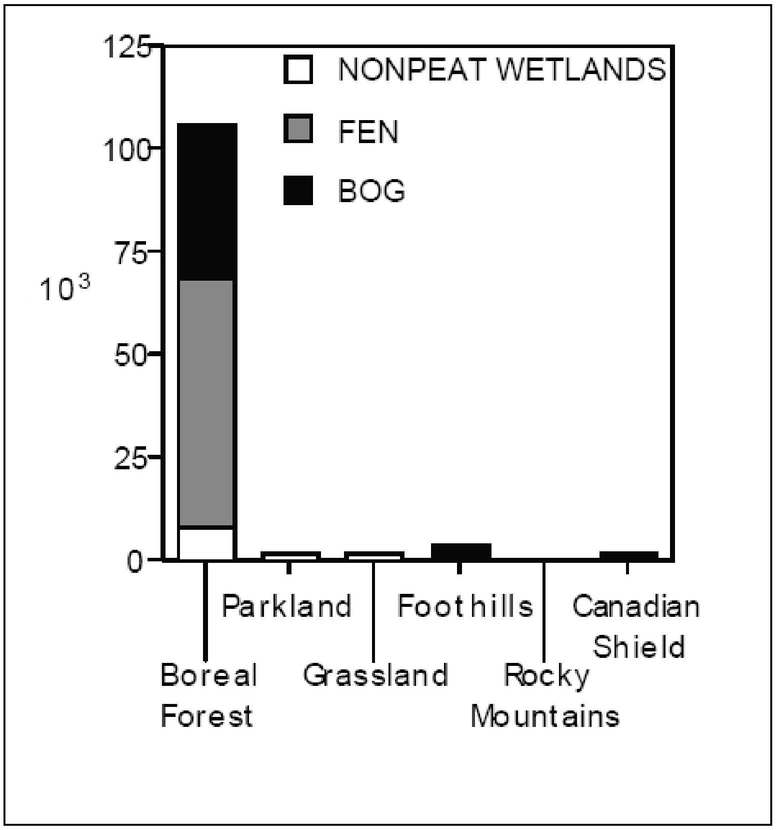

Figure 2: Wetland area (in 10^3 km^2) for the six ecological regions of Alberta (Hasley 2007)

2.3 Hydrology

2.3.1 Landscape level hydrology

Devito et al. (2005) found that the most important factors to consider (in descending order of importance) when managing hydrology at a landscape scale are climate, bedrock geology, surficial geology, soil type and depth and, finally, topography and drainage network.

The climate of the boreal plains is sub-humid, meaning precipitation is less than evapotranspiration. In a sub-humid climate soil water storage is a dominate factor in hydrology, while runoff is important in humid climates (Devito et al. 2005). Because most techniques for restoring wetlands (especially peatlands) have been created for humid environments, new techniques which do not rely on capturing runoff may be need to be developed for wetland restoration in sub-humid environments.

The bedrock and surficial geology of the boreal plain is complex due to the high amount of vertical flow and the thick surficial deposits on permeable, heterogeneous bedrock (Devito et al. 2005). The hydraulic interconnectivity and heterogeneity of this landscape render catch-all techniques for restoring hydrology impractical. In such complex systems, groundwater flow modeling is extremely useful for understanding possible outcomes of disturbances and for locating less sensitive areas (Devito et al. 2005).

Lowland organic soils of wetlands in the boreal plain are dominated by return and surface flow. The upper layer of the organic soil has a high hydraulic conductivity which allows for a quick dissipation of excess water without a significant rise in water level (Wheeler 1999). These wetlands should be considered key runoff-generating areas that dominate regional water balances (Devito et al. 2005). More detailed information on the hydrology of peatlands is described in the next section.

Topography is also an important factor contributing to hydrology of a wetland. The g**eologic setting** creates the ponding of water (water storage), or brings water to the surface to provide the physio-chemical environment for wetland biota (Devito & Mendoza 2006).

2.3.2 Peatland hydrology

Peatlands are important ecosystems on a global level due to their role in stabilizing water levels and storing carbon (Rydin & Jeglum 2006). The diplotelmic structure of peatlands is vital to these functions as it regulates water storage and discharge, thus creating constantly saturated conditions ideal for carbon storage (Price et al. 2003). This structure is composed of a two-layered soil structure, the *acrotelm* and the *catotelm*.

The acrotelm is the uppermost layer of the peat deposit and is composed of live and slightly decomposed vegetation. It is characterized as having a variable water content, high hydraulic conductivity, periodic aeration and intense biological activity (Ivanov 1981; Ingram 1983). The catotelm, the lower level of more decomposed peat, is characterized by constant water content, very low hydraulic conductivity, and anaerobic conditions. Carbon is sequestered by the submergence of organic matter at the base of the acrotelm, or, as seen from the opposite perspective, by the thickening of the catotelm (Clymo 1984).

Natural peatlands depend on this structure to regulate storage and discharge of water (Price et al. 2003). A combination of high hydraulic conductivity and high specific yield means that the acrotelm allows for the rapid dissipation of water excess without a significant rise in water level (Wheeler 1999). Specific yield is the amount of water that will drain from an area under the forces of gravity.

The presence of bryophytes is also an important component to a peatland's ecosystem functioning (Vitt 2000). *Sphagnum* is especially important to acrotelm hydroregulation because the loosely woven, expansible surface creates the capacity to store large amounts of water (Clymo 1982). *Sphagnum* mosses and some species of brown mosses possess properties that create an acidic, nutrient poor, heat-insulating, and slowly permeable environment, ideal for peat accumulation (Andrus 1986; Rochefort 2000). It is not clear whether an acrotelm dominated by graminoids or tree species has a comparable capacity (Wheeler 1999).

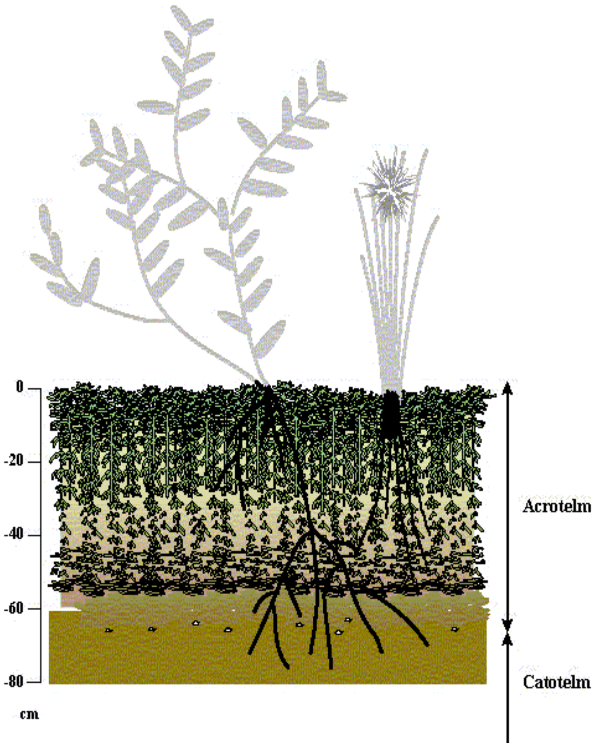

Figure 3: Diagram of the acrotelm and the catotelm (Campbell & Rochefort 2001).

Hydraulic movement within peatlands is dynamic. Devito et al. (1997) and Fraser et al. (2001) found that groundwater flow in peatlands can switch from recharge to discharge for periods when evapotranspiration is higher than precipitation. This groundwater movement may be important for the redistribution of nutrients and limiting substrates in peatlands which are isolated from regional ground water (bogs) (Fraser et al. 2001).

2.4 Natural successional development of peatlands in Alberta

In continental western Canada, peatland initiation began approximately 6000-7000 BP through paludification (Nicholson & Vitt 1990). Peatland development does not follow a single successional pathway; however, most North American peatlands were initiated from floating rafts of sedges, rushes and grasses, which formed sedge peat at the bottom of peat massif (Kuhry & Nicholson 1993). The peat gradually accumulates to a thickness where the top layer no longer has contact with groundwater, making precipitation the only water source. This creates a nutrient poor, ombrotrophic peatland, where acidophilic plants, such as *Sphagnum* moss, slowly replaced herbaceous sedge plants and brown mosses.

2.5 Wetland sensitivity

The sensitivity of boreal wetlands to disturbance can be summarized using two interconnected criteria: the degree of hydraulic connectivity and the resilience of the soil and vegetation (Hill & Devito 1997). Resiliency is the capacity of a system to withstand disturbance without shifting to a different state (Swedish Environmental Advisory Council 2002). Hydraulically connected wetlands have soil and vegetation that has been shaped by annual or decadal variation, leading to a resilient system. In such systems, the restoration of a natural hydraulic flow is paramount. Disturbances in systems that have an isolated hydrology will only change directly affected areas, not the entire system. On the other hand, these systems have developed in isolation and are less resilient to disturbance.

Trees and mosses are examples of vegetation which are more sensitive to disturbance. Mosses are sensitive to shifts in water chemistry and hydrology because they lack vascular systems and absorb water and nutrients through their unicellular tissue (Clymo & Hayward 1982). Trees are sensitive to change because they are woody and will need longer to regenerate than herbaceous plants.

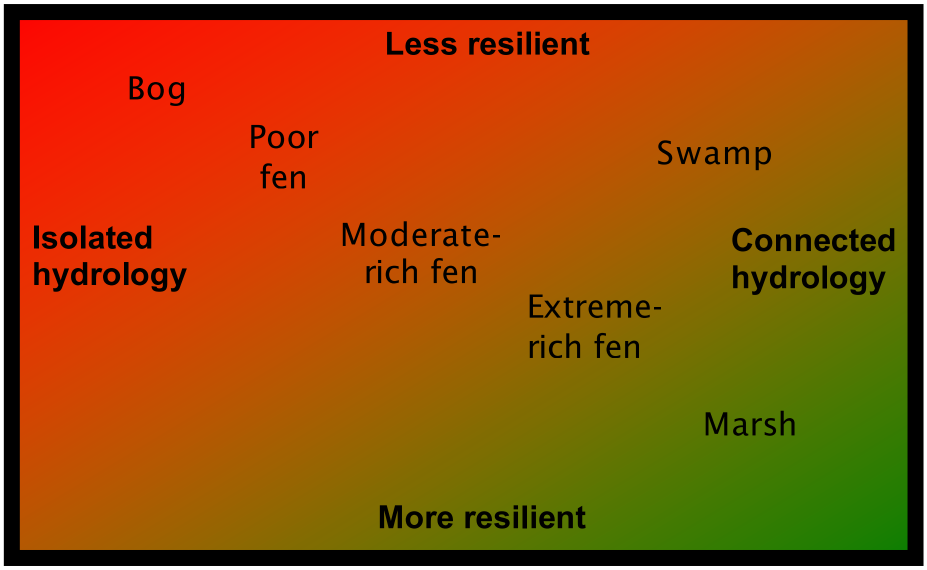

Figure 4. An overview of which wetlands are more sensitive to change according to the amount of hydraulic connectivity and resilience of the soil and vegetation. Bogs are the most sensitive systems and marshes are the least sensitive (Adapted from Trettin et al. 1997).

3. Energy sector disturbances: impacts and best management practices

The major disturbances created by oil, gas and in situ oil sands development are seismic lines, pipelines, roads and well pads (Turchenek 1990; Schneider & Dyer 2006). Steam extraction methods used for in situ oil sands extraction also use large amounts of water; approximately 2.5 m^3 water is needed to extract 1 m^3 oil (Schneider & Dyer 2006). Because about 90% of this water is recycled, the actual amount of water needed to produce a m^3 of oil is between 0.25 and 0.5 m^3. However, this 10% - 20% will be continually drawn over the the entire lifespan of an operation (approximately 40 years) (Opti Canada & Nexen 2006). Schneider and Dyer (2006) suggest altetrnative techniques for in situ oil extraction, such as VAPEX, in situ combustion, and electrical heating, would greatly reduce water and energy requirements. A number of in situ oil sands operators are assessing and adopting some of these methods (Southern Athabasca Oil Sands Producers 2007).

In the following sub sections, each disturbance and its potential impact on wetlands is described. Information on which wetlands are most sensitive to this disturbance as well as best management practices (BMP) for footprint reduction are also provided. Although many documents outline BMPs for oil and gas development in wetlands, there is no evidence that these practices have been proven through research trials. BMPs listed in this document are intended to provide a starting point, but research which tests these practices in different types of wetlands is needed.

Throughout the rest of this document, emphasis will be put on peatlands because these wetlands are the dominant wetlands in northern Alberta (Figure 2).

3.1 General effects of linear developments

Linear constructions, such as seismic lines, pipelines and roads may result in a significant loss of biodiversity at local and regional levels because of restricted movement between populations, habitat fragmentation and increased human and predator access (Findlay & Bourdages 2000). In forested ecosystems, fragmentation is considered one of the primary causes of species extinction (Wilcox & Murphy 1985). Linear constructions have a proportionally large edge effect compared with other disturbance geometries (Collinge 1996; Tromboulak & Frissell 2000). The edge effect describes the area around a disturbance that is affected by changes in physical or chemical conditions, predation patterns, and animal behavior (CAPP 2004). As changes to physical and chemical conditions depend on the disturbance, they will be discussed separately for each disturbance. Boreal wildlife avoid areas near linear developments. Dyer et al. (2001) observed that Caribou avoid habitat within 250 m of roads. Similarly, boreal birds avoid suitable habitat up to 100 m from roads, pipelines and seismic lines (Schneider & Dyer 2006). Furthermore, the effects of roads on the biodiversity of plants and reptiles may be undetectable for decades (Findlay & Bourdages 2000). Reducing fragmentation via restoration of linear features within the boreal is therefore desirable.

3.2 Seismic lines


Schneider & Dyer 2006

Seismic lines are one of the most dominant man-made features in northern Alberta (Figure 5) (McFarlane 2003). They allow the oil and gas companies to inventory the subterranean reserves by measuring impulses from underground explosions (Schneider & Dyer 2006). Traditionally, seismic lines are created by bulldozers which clear vegetation in strips (6 m to 8 m wide and several kilometers long) (Government of Alberta 1998). The bulldozers remove topsoil, including any trees or stumps. These strips are cut every 400 m to 100 m, creating a grid system across the landscape (McFarlane 2003). Increasingly, 3D seismic models are needed to accurately place horizontal wells. This requires a much tighter grid system (every 60 m at Long Lake) (Schneider & Dyer 2006). At such high densities, it is important that companies use methods which will have the lowest impact on the system and actively restore the lines after use. The seismic lines are intended to be used once and then left to regenerate (McFarlane 2003).

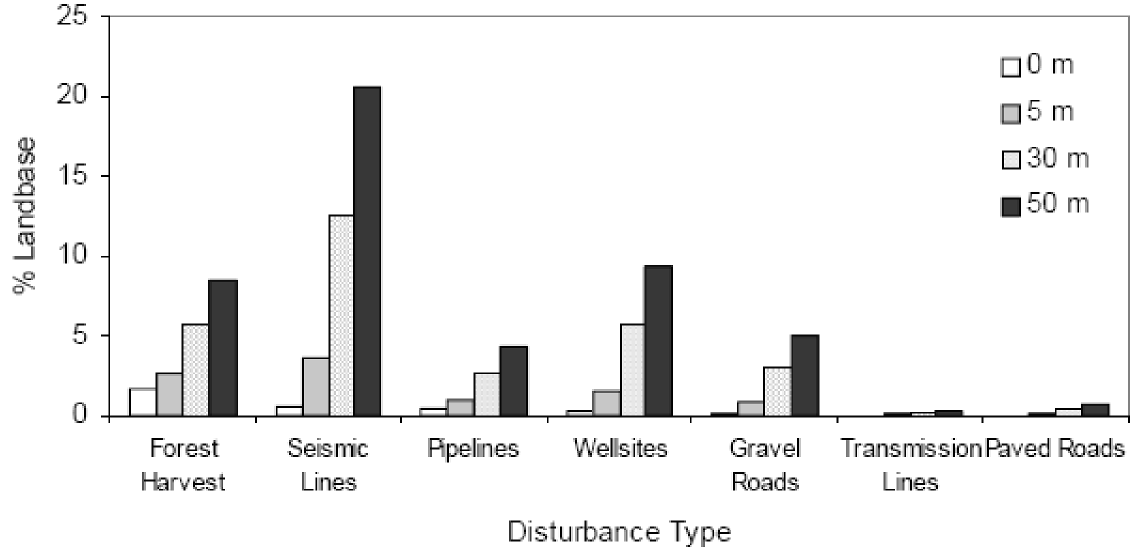

Figure 5: The percent of land base affected by each disturbance without edge effect (0m) and with edge effects of varying widths (5, 30 and 50 m). All disturbances are located within the 6 million hectare FMA area of Alberta-Pacific Forest Industries (McFarlane 2003).

In recent years, low impact seismic (LIS) techniques have become the norm for many companies (McFarlane 2003). These techniques reduce the environmental impact by reducing the width of the lines to between 2 and 4.5 m (ASRD 2006). Instead of straight lines, LIS lines meander, avoiding valuable timber and reducing the line-of-site to a maximum of 200 m (ASRD 2006). Low ground pressure bulldozers are used to minimize the impact to soil and vegetation (McFarlane 2003).

New equipment allows the reduction of seismic lines to as little as 1.75 m in width. These narrow mulchers clear lines by mulching small trees and bushes (McFarlane 2003; CAPP 2004). Helicopter-carried equipment and hand-cut lines have the smallest impact on the land and are used in areas where the appearance of seismic lines is a major concern (McFarlane 2003).

In peatlands, seismic lines are cut mainly in winter and physical changes in the peat deposits are assumed to be minimal (Turcheneck 1990). However, Lee and Boutin (2006) found that lowland black spruce forests (wooded bogs) did not recover, even after 35 years. Lee and Boutin (2006) hypothesized that the removal of hummocks reduced the safe sites for black spruce germination. Furthermore, the seismic lines changed the local hydrology through the 'flattening' of the surface, peat compaction and decreased evapotranspiration due to the removal of shrubs and trees (Turcheneck 1990; Lee & Boutin 2006). Areas affected by seismic lines were converted from dry, woody communities to wetter sedge-dominated communities, effectively setting the successional clock back to the peatland's earlier minerotrophic state.

Unfortunately, Lee and Boutin (2006) only looked at black spruce regeneration, assuming that tree establishment and growth are the most important indicators of ecosystem recovery. However, in bogs, *Sphagnum* is the keystone species and is the best indication of a functioning peatland ecosystem (Rochefort 2000). Lee and Boutin (2006) did not report what ground vegetation was found on the seismic lines. Therefore, although these sites have suffered damage, saying there has been 'no recovery' might be an overstatement.

It has been shown that forbs readily recolonize these areas (McFarlane 2003; Lee & Boutin 2006), so marshes are probably not as susceptible to long-term degradation as shrubby and woody peatlands. If mosses, especially *Sphagnum* in poor fens and bogs, recolonize the seismic lines, active restoration measures may not be necessary. Mosses, the main driver in peat accumulation (Vitt 2000), grow more quickly, without competition for light (Berendse et al. 2001; Limpens et al. 2002; Pauli et al. 2002). The faster rate of peat accumulation will translate to a faster succession back to a forested bog. Research is needed which examines the ground cover of wetlands affected by seismic lines to see if mosses generally naturally revegetate or whether they should be actively reintroduced.

Various best management practices (BMPs) have been developed to minimize the impact of seismic lines on the boreal landscape.

- Use existing seismic lines and trails wherever possible to minimize disturbance. (B.C. Ministry of the Environment 2008).

- Minimize the width of seismic lines. (CAPP 2004; B.C. Ministry of the Environment 2008).
- Use mulchers to encourage natural revegetation of seismic lines (CAPP 2004).
- Use geo-positioning technologies to allow a seismic line to 'meander,' thereby reducing the line-of-sight (CAPP 2004).

3.3 Buried Pipelines

Pipeline right-of-way crossing peatlands in northern Alberta (http://cgc.rncan.gc.ca/permafrost/wheredoes_e.php).

Buried pipelines are also a significant man-made disturbance in northern Alberta (Figure 5) (McFarlane 2003). They are constructed by first stripping the topsoil and then digging a trench (Ryder et al. 2004). Then the pipelines are stringed, welded, coated, and deposited in the trench. The soil that was removed by trenching is backfilled and the area is reseeded with appropriate vegetation (Ryder et al. 2004).

Aside from the general linear effects discussed in section 3.1, pipelines alter hydrology, thermal regime, soil structure and vegetation (Ryder et al. 2004; Sakhalin Energy 2005). Hydrology is altered mainly through changes in localized interception and/or disruption of flow within the peat (Sakhalin Energy 2005). Conventional pipe laying causes the peat layers to be mixed, affecting the flow of water through peat (Ryder et al. 2004). Once peat is removed from the peatland it will quickly dry out, making it more vulnerable to erosion. Due to erosion and compaction, the amount of peat used for backfilling will likely be less than the amount removed. After further settling of the pipe, a linear depression often forms over the pipe which acts as a passage for water flow, causing further erosion (Ryder et al. 2004).

Changes to the thermal regime are caused by modifications in the soil structure, the removal of surface vegetation and pipelines themselves, as they are a heat source (Sakhalin Energy 2005; Naeth et al. 1993). Temperature changes can lead to the degradation of permafrost zone of peatlands (Turcheneck 1990). Removal of the vegetation layer (acrotelm) increases insolation and could lead to intensification of frost penetration during the winter and resulting erosion during the summer (Dykes & Gunn 2004; Sakhalin Energy 2005).

Pipelines through peatlands also create the potential for hydrocarbon spills. Spills are more likely in peatlands because peat stresses the pipelines more than mineral soils. Many types of peat exhibit negative buoyancy, putting upward pressure on pipelines and causing stress on the pipe (Ryder et al. 2004) Additionally, peat is highly acidic and can quickly corrode pipes (Ryder et al. 2004). A common approach to addressing pipeline buoyancy is to weight the pipe, which reduces the buoyancy-caused stress (Jon Gareau, CNRL, personal communication).

The reclamation of oil-contaminated peatlands will differ from upland sites because of cold, wet peat soils, a different plant community, and the high acidity and low nutrient level of the soil (Canadian Petroleum Association 1987). One of the major cleanup problems in peatlands results from the fact that oil becomes trapped in voids or between organic layers and can be difficult to remove and recover (Canadian Petroleum Association 1987).

The following BMPs will help mitigate the effects mentioned above.

- Avoid wetlands as much as possible (Ryder et al. 2004).
- Use machinery which has a low impact on wetlands, i.e. tracked excavator (Martin 1994; Dykes & Gunn 2004)
- Do work in the winter, keeping the frozen blocks of the acrotelm in place and replacing them after the pipe trenches have been backfilled with peat (Sakhalin Energy 2005).
- Do not mix the acrotelm and catotelm of the peatlands when excavating (Ryder et al. 2004; Sakhalin Energy 2005). Mineral soil, if encountered should be stored separately from peat (Sakhalin Energy 2005). These layers should then be put back in the order they were previous to trenching: mineral soil at the bottom, then catotelm and lastly the acrotelm (vegetation layer) last.
- Work on short sections at a time to minimize the amount of peat exposed (Ryder et al. 2004; Sakhalin Energy 2005). No more trench than can be filled within a day should be opened. Progress across a peatland should be no more than 450 m per day (Sakhalin Energy 2005).
- To reduce disturbance to the peatland’s thermal regime, bury pipes at a minimum of 1.2 m depth to top of pipe (peatland freezing depth is between 30 cm and 80 cm) (Sakhalin Energy 2005).
- In order to minimize effects on the hydrology, install pipelines in the mineral soil below the peatland’s main zone of water movement (Ryder et al. 2004; Sakhalin Energy 2005).
- Geotextile products and porous polypropylene materials may be used in peatlands to increase the load bearing capacity, prevent mixing of subgrade and fill; and, allow for the passage of water (CAPP 2001).

No research was found on the effects of pipelines on wetlands in the boreal region. However, CAPP (2001), states that peatlands areas generally do not require reseeding since natural revegetation is often adequate. Rury and Little (1989) showed that marshes where pipelines were installed revegetated quickly (within one growing season) in Northeastern USA. Peatlands with thinner peat deposits (fens) are likely to be less sensitive to pipeline thermal and hydrological disturbances because the pipelines can be placed in the mineral soil below the peat deposits (Dykes & Gunn 2004).

3.4 Roads

Roads constructed through wetlands are more damaging than seismic lines or pipelines because they disturb regional water flow, destroy local habitat, compact the underlying peat and contaminate nearby vegetation with road dust (Turcheneck 1990; Tromboulak & Frissell 2000; Nugent et al. 2003).

Two types of roads are constructed by the energy sector: all-weather roads and winter roads. All-weather roads can be accessed all year and are constructed by first laying down a geotextile material and then a layer of mineral or clay soil (Jos Lussenburg, Japan Canada Oil Sands, personal communication). Winter roads are much less invasive because they are only used in the winter months when the ground is frozen, greatly reducing the amount of compaction. No geotextile or mineral soil is applied.

Roads can change the hydrology of a wetland by creating a barrier to surface, and in some locations, groundwater flow (Devito & Mendoza 2007). Even winter roads constructed across peatland areas can effectively limit the flow of water through a bog area for a prolonged period of time (Archibald et al. 1997). Altering the hydrological regime of the wetland changes the chemistry and, consequently, the vegetation. For example, nutrient-rich water from fens or a mineral terrain could be diverted onto an ombrotrophic bog (Turcheneck 1990). Receiving nutrient-rich water will quickly lead to the degradation of a bog system as high concentrations of nutrients are toxic to *Sphagnum* mosses (Clymo & Hayward 1982). On the other hand, building a road through a rich fen could block groundwater flow, meaning the fen downstream of the road would become a poor fen (Turetsky & St. Louis 2006). In permafrost peatlands, frequent ponding will degrade the underlying permafrost, creating a thermokarst terrain (Turcheneck 1990). No research was found which directly measured the effects of roads on wetland hydrology.

Dust from roads affects bordering vegetation. Moss-dominated wetlands will be especially sensitive as mosses have no root system and absorb water and nutrients directly through their tissue. Spatt and Miller (1981) found that *Sphagnum* sp. growth was impaired due to road dust on the Alaska Pipeline haul road. Faubert and Rochefort (2002) also found in a greenhouse experiment that the growth *Sphagnum* species and true mosses was impaired by peat deposition, which occurs when dried peat from harvested peatlands is blown on to restoration areas. Their growth diminished after being buried by 10 mm or more of peat.

As destructive as roads are, they are necessary in a modern world. Nevertheless, their impact can be minimized through BMPs. Phillips (1997) and B.C. Ministry of the Environment (2008) provide detailed guidelines for the construction of roads through wetland. Below is a summary of the most important BMPs.

- Decrease the amount of roads needed by integrating land use with other land users (i.e. forestry sector) (CAPP 2004).
- Avoid constructing roads through wetlands unless there is no practical alternative (Uplands are less sensitive and roads will be easier and less expensive to build) (Phillips 1997; B.C. Ministry of the Environment 2008).
- If a road must be constructed through a wetland, try to construct the road parallel to water flow (B.C. Ministry of the Environment 2008).

- Use geotextile membranes to protect peat for temporary access roads (Ryder et al. 2004).
- Use timber mats to protect against compaction (Ryder et al. 2004).
- Remove vegetation (acrotelm) layer when constructing the road to protect this layer from compaction and contamination with mineral soils. The vegetation can be stored for restoration if the life-span of the road is short or used for the restoration of other decommissioned installations if the lifespan is longer (Ryder et al. 2004).
- Design upland road approaches to wetlands so that the surface runoff carrying sediment is diverted before entering the wetland (Phillips 1997; B.C. Ministry of the Environment 2008).
- Do not construct roads during a time that is critical to local wildlife (i.e. mating or migration time) (CAPP 2004; B.C. Ministry of the Environment 2008).
- Minimize the width of the road (B.C. Ministry of the Environment 2008).
- Design the road to follow the contour of the landscape to decrease erosion (B.C. Ministry of the Environment 2008).
- Preserve natural hydrology by creating cross drainage to maintain natural surface and subsurface flows. This can be done by (a) using construction methods that allow free water flow throughout the roadbed or (b) placing culverts at each end of each wetland crossing and at low points in between. Culverts should be spaced a maximum of 91 m apart to ensure adequate cross drainage through the road bed (Phillips 1997; B.C. Ministry of the Environment 2008).
- Install culverts in peatlands that are a minimum of 61 cm in diameter buried halfway below the soil surface. The upper half handles surface storm flow and the lower half cross drains everyday subsurface flows. If the culverts are not buried, subsurface flow will pond up stream of the road and could affect trees (Phillips 1997).
- Construct ditches in wetland crossings to allow surface and subsurface water (top 30 cm) to flow to, through and then away from culverts. For shallow peat

(<1.2 m) ditches should be constructed immediately adjacent to the toe of the fill slope. For deeper peat (≥1.2 m) the space between the toe of the slope and the ditch should be three times the depth of the peat. This minimizes damage to the strength of the top layer containing root material (Phillips 1997).

- Construct roads with clean fill or other suitable native materials to reduce the spread of invasive species (Phillips 1997; B.C. Ministry of the Environment 2008).
- Control entry to operational areas to minimize access (CAPP 2004; B.C. Ministry of the Environment 2008).
- Cease using equipment on frozen roads where rutting exceeds 15 cm depth for continuous distances greater than 91 m. This will reduce the impacts on hydrology by reducing compaction and preventing water from channeling in ruts (Phillips 1997).
- Whenever possible, roads which are no longer needed should be removed and restored (Phillips 1997; CAPP 2004; B.C. Ministry of the Environment 2008).

3.5 Well pads


T. Osko

Facilities for oil and gas extraction is constructed on areas called well pads. Conventional oil well pads are approximately one hectare; however, in situ oil sands pads can typically range from four to ten hectares or more because multiple wells are installed on the same pad. For the construction of a pad on shallow peat, 40 cm of peat is excavated and deep fill is laid down in layers and compacted (MEG Energy Corp. 2008). A mineral soil cap is installed above the compacted layers. The excavated peat is stored as replacement material for reclamation (Opti Canada & Nexen 2006; MEG Energy Corp. 2008).

For deeper peat deposits, floating pads are constructed (see Figure 6). No peat is excavated for such pads. A prefabricated drainage composite or log-built corduroy is laid directly on the peat surface followed by a geotextile material. A clay cap will be placed in compacted layers (typically to a meter or two above original surface) on top of the geotextile material (Opti Canada & Nexen 2006). The cap will then be graded and covered with gravel. Berms are constructed around all well pads for internal drainage. A second external ditch is constructed outside the berm in the peat (Opti Canada & Nexen 2006).

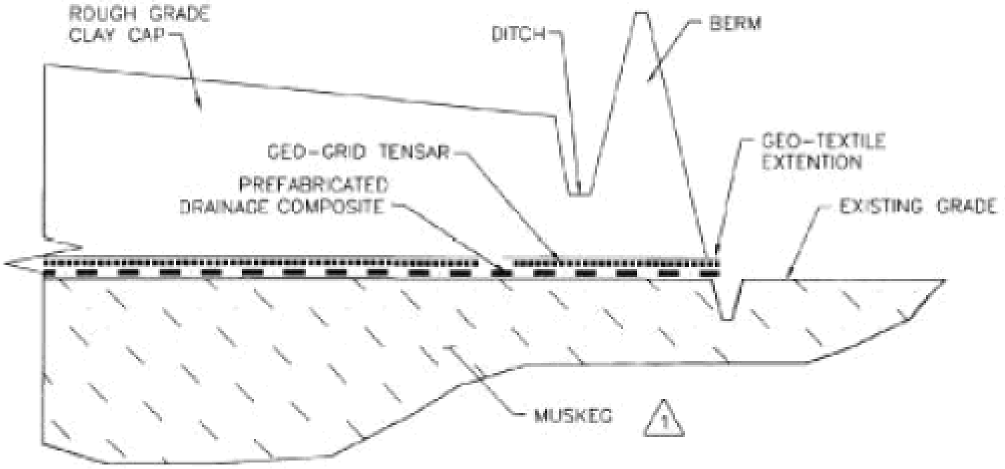

Figure 6: Cross-section of a floating well pad constructed on a peatland (Opti Canada & Nexen 2006).

Well pads adversely affect the wetland within which they are placed by destroying the habitat immediately beneath the pad, altering the hydrology and possibly contaminating adjacent wetland areas. The hydrology is changed through the removal of peat and the compaction of the underlying peat. As with pipelines, the peat could be contaminated with hydrocarbons in the event of a leak or oil spill. The peat could also be contaminated with mineral or clay soil if the internal drainage of the well pad is not properly designed and the mineral or clay cap erodes onto the peatland. The following BMPs will reduce these impacts.

- Reduce well pad size (CAPP 2004).
- Construct pads with multiple wells to reduce the construction of pipelines and roads (CAPP 2004).
- Surface drainage structures (e.g., berms) should be constructed to intercept and divert runoff, preventing erosion of the well pad (B.C. Ministry of the Environment 2008).
- Insert oil-absorbent matting to catch grease and oil around the drill rig (B.C. Ministry of the Environment 2008).
- Use winter pads wherever possible (Peterson 1996).
- Remove vegetation (acrotelm) layer when constructing well pads to protect this layer from compaction and contamination with mineral soils. The vegetation can be stored for restoration of the disturbed area or used for the restoration of other decommissioned installations (Ryder et al. 2004).

3.6 Peat compaction

All of the above-discussed disturbances lead to varying degrees of peat compaction. Constructions on peatlands require the removal of the vegetation layer (acrotelm). The removal of the acrotelm profoundly affects the water storage capacity, the nature and magnitude of evaporation losses as well as soil processes, including carbon storage (Price et al. 2003). The natural drainage around installations such as roads and well pads are altered, potentially draining some areas while flooding others. Drained peat undergoes subsidence in the unsaturated zone and compression in the saturated zone, which greatly changes the soil pore structure. The change in pore structure decreases the water storage capacity and hydraulic conductivity which exacerbate the fluctuation of the water table (Price et al. 2003). Compression and oxidation can decrease hydraulic conductivity by

75% (Price et al. 2003). All of these factors create conditions which are unfavorable to the establishment of plants, especially peatland bryophytes.

4. Restoration of boreal wetlands

4.1 Ecological restoration

Degraded systems can recover through active restoration, rehabilitation or replacement measures or they can recover passively through self-regeneration (Figure 7) (Bradshaw 2000). Ecological restoration returns an ecosystem to its prior state to the extent that the state can be ascertained and then approximated through restoration measures (Clewell & Aronson 2007). Restoration focuses on the return of the previous ecosystem’s structure and function (Figure 7) (SER 2004). Rehabilitation is a restoration attempt that is not completely successful (Bradshaw 2000). Reclamation is an older term used to designate the conversion of lands thought to be useless to a more productive condition (i.e. forestry or agricultural use) (Clewell & Aronson 2007).

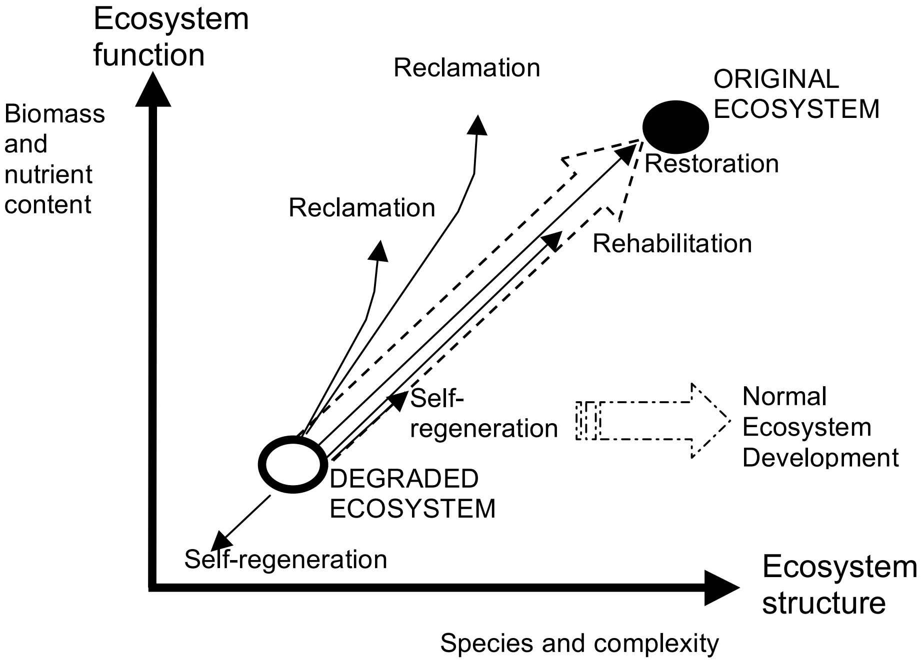

Figure 7: When an ecosystem is degraded through mining or other operations, the ecosystem structure and functions are often reduced. The first option for such a degraded ecosystem is to do nothing (allow self-regeneration), which may result in slow recovery or allow the system to degrade further by means of erosion. The second option is to take active steps to aid the system's recovery. If the recovery is completely successful, then restoration was achieved. If the actions were not entirely successful, then rehabilitation was accomplished. The third option is reclamation in which an alternative (often seen as an improvement) to the original ecosystem is produced (Adapted from Bradshaw 1987).

Self-regeneration implies minimal human intervention. Allowing self-regeneration may lead to more stable, better acclimated vegetation communities and cost less than active, imposed restoration strategies (Bradshaw 2000; Prach et al. 2001). For example, some disturbed sites are able to naturally revegetate due to the presence of an active seed bank or encroachment from adjacent remnant sites (Middleton 1999). In certain cases, however, ecosystems are not able to return to their historical trajectory without active restoration measures. The most effective and economical restoration methods involve a combination of limited treatments of critical factors and leaving natural processes to take care of the rest (Bradshaw 2000). Some critical factors for the restoration of boreal peatlands affected by energy sector disturbances are outlined in table 3.

Table 3: Important processes on degraded land and possible solutions.

Process	Problem	Solution
1. Immigration of appropriate plant species	Not enough appropriate species	Introduction by seed or plants
2. Establishment of appropriate plant species	Adverse site conditions	Rewetting, providing a mulch or a nurse plant
3.Immigration of soil flora and fauna	Slow immigration of certain species	Inoculate with soil especially containing mycorrhizae, and appropriate microorganisms
4. Changes in soil structure and function due to plant and soil organism activity	Slow development	Ensuring a vigorous plant growth to provide root activity and organic substrates
5. Reduction in toxicities	Excess acid Excess metals	Introduce tolerant species add minimal lime Introduce tolerant species, add P and organic matter
6. Physical improvements to texture and structure	Excess compaction Lack of soil structure	Remove compaction by ripping Make sure 1-5 are operating to maximal extent
7. Accumulation of peat	Dry conditions, lack of peat–accumulating plants	Rewetting, reintroduction of appropriate peat-accumulating plants

(Adapted from Bradshaw 2000)

Rochefort (2000) defines the goals of peatland restoration in North America as reestablishing a) a plant cover dominated by Sphagna or brown mosses, depending on the status of the residual peat and b) the diplotelmic hydrological layers (acrotelm and catotelm) that characterize intact ‘active’ peatlands. The achievement of these goals will imply an adequate level of productivity, returning the mined site to a peat accumulating system, re-establishing the cycling of nutrients, returning a vegetation structure and microhabitats from which emerge faunal and floral diversity, and making sure that the ecosystem is resistant to biological invasion in the long term (Rochefort 2000). These short term goals can be reached within 5 years, while the long-term goals might take up to 30 years to return to a system (CEMA 2006).

4.2 Restoring hydrological function

Restoring hydrological functioning should be the first consideration in wetland restoration (Whisenant 1999; Biebighauser 2007). Keddy (1999) estimated that hydrology is the single most important environmental factor (50 percent relative importance) in controlling plant community structure. The hydrological regime is the most important factor in the establishment and maintenance of wetland types and processes. Hydrology greatly affects chemical and physical properties such as nutrient availability, soil salinity, sediment properties, pH and the degree of anoxia (Mitch & Gosselink 2000). Water inputs are a major source of nutrients and cations to wetlands (except ombrotrophic bogs which only receive nutrient-poor rainwater) (Drexler & Bedford 2002). Restoring the hydrological regime is necessary for the establishment of target vegetation, nutrient cycling and increasing energy capture rates of wetlands (Mitch & Gosslink 2000). A number of techniques used to restore wetland hydrology are outlined below.

- Blocking drainage ditches is an important step in restoring wetland hydrology (Cooper et al. 1998; Price et al. 2003). This simple step will retain surface water and elevate the ground water level.
- Creating depressions and altering the basin morphology is common for the construction of wastewater wetlands and has also been suggested for peatland restoration (Wheeler & Shaw 1995). This would involve removing the clay/mineral cap and reprofiling the peat surface so that the water table level would be closer to the surface.
- Shallow retention basins (< 20 cm) increase soil moisture and water table, thereby improving the establishment and growth of *Sphagnum* mosses in bog restoration projects (Price et al. 2002).
- Berms, bunds, terracing and polders hold surface water and precipitation on site and are important in retaining snow melt water in the spring on cutover peatlands (Price et al. 2003).
- The use of mulch or nurse plants increases the moisture level of the microclimate on the peat surface by increasing the relative humidity near the surface and

decreasing the evaporation loss compared to a bare peat site (Price et al. 2003; Groeneveld & Rochefort 2005).

- Border and pipe irrigation can be used to maintain water levels (Richert et al. 2000; Rochefort 2001). However, such measures should be avoided, as they are costly and not sustainable. Additionally, moving water and sedimentation will impair the establishment of mosses (Quinty & Rochefort 2000).

It is not possible to create a universal formula for restoring the hydrology of wetlands affected by energy sector disturbances. Each site has site-specific factors which should be taken into consideration when restoration strategies are being considered. Such factors include duration of activity, size of disturbance, presence of absence of filter material, topography, characteristics of the substrate, climate and the objectives of the restoration project (Wheeler & Shaw 1995; Rochefort et al. 2003, Imperial Oil Resources 2006).

4.3 Restoring vegetation

Vegetation plays an essential role in the restoration process of peatlands because the ecological functions of the top peat layers depend on the species composition. Therefore, the establishment of the appropriate species is imperative for the return of the ecosystem functions.

When natural wetlands are nearby and wetland hydrology has been restored, a restoration site may be recolonized by wetland species without implementing reintroduction techniques. Golder Associates (2003) assessed the potential for natural recolonization in wetlands in the oil sands region. They found that 29 species naturally recolonized the site without active reintroduction measures. Twenty-one of these species were wetland species including five *Carex spp., Scirpus validus, Typha latifolia, Utricularia minor, Hippuris vulgaris,* and *Puccinellia nuttalliana.* On cutover and cutaway peatlands, vascular plants were capable of naturally recolonizing sites, but bryophytes were not (Poulin et al. 2005; Graf et al. 2008).

In some cases, species may need to be actively reintroduced to restore ecosystem function and/or structure. If active measures must be taken to establish the target vegetation, the following techniques may be used: direct placement of donor seed banks, transplanting plugs or rhizomes.

Introducing a donor seed bank means transporting the surface layer and rooting zone of a donor plant community to the restoration site. A seed bank contains a variety of species and types of propagules including seeds, rhizomes, stolons, and diaspores. Seed banks also include soil mycorrhizal fungi which may improve plant growth in soils toxified by heavy metals and salts (Kernaghan et al. 2002). The application of a donor seed bank has been successful in the restoration of marshes (Brown & Bedford 1997) fens (Patzelt 1998; Cobbaert & Rochefort 2004; Graf & Rochefort 2008) and bogs (Rochefort et al. 2003),.

Transplantation is often used for plants that do not establish well from seeds, as is the case for many wetland species (Cronk & Fennessy 2001). Mature plants tend to be more tolerant of extreme environmental conditions (Middleton 1999). Transplanting of rhizomes or plugs of plants has been an effective technique for establishing a wide assortment of wetland species (van der Valk et al. 1999; Cooper & MacDonald 2000; Kratz & Pfadenhauer 2001).

Seeding plants is an easy and inexpensive option; however, this technique often produces poor results for wetland plants (Patzelt 1998; Cooper & MacDonald 2000; Cronk & Fennessy 2001). Seeds can be collected by hand from nearby sources or purchased from specialty nurseries. Ideally, seeds should be local to ensure that they are genetically adapted to the local conditions (Falk et al. 2006). The timing of collection is vital as seeds should be collected just as they mature but before they fall to the ground. After collection, close attention must be paid to species-specific requirements for storage and germination. The methods for storing seeds can greatly affect their viability (van der Valk et al. 1999). Baskin and Baskin (1996) and Middleton (1999) provide detailed information on the storage and germination requirements of wetland species.

4.4 Existing research

4.4.1 Reclamation of energy sector disturbances on Alaska's North Slope

Alaska's North Slope, also a landscape dominated by wetlands, has been subject to extensive oil development. Between the late 1970's and early 1990's the United States Department of Army issued permits allowing over 8,500 ha of wetlands to be filled with gravel from decommissioned road and well pad construction (Peterson 1996). In the 1990's federal and state agencies put policies into place which required wetland sites to be restored. The two main strategies used for restoration were 1) revegetation of gravel to kick start succession towards a tundra vegetation community, and 2) reclamation of contaminated soils from oil spills (Jorgenson & Joyce 1994).

In restoration projects the revegetation of the gravel sites was generally successful. A major objective for revegetation is to create a barrier to prevent seed from surrounding natural vegetation from blowing away and to collect snow which acts as thermal protection during the harsh winter months (Peterson 1996). Some of the main plant species used were graminoids (i.e. *Carex aquatilis*, *Eriphorum angustifolium*, *Dupontia fisheri*, *Poa glauca*, *Festuca rubra*), willows (*Salix ovalifolia*, and *S. reticulate*), and mosses (*Sphagnum* sp.) (Shirazi et al. 1998). The application of two to six feet of overburden improved regeneration success by increasing moisture retention and aeration for seed establishment (McKendrick et al. 1992).

Revegetation projects were much more successful when fertilizer was used. Due to low concentrations of mineralized nitrogen and phosphorus in tundra soils, revegetation attempts that did not use fertilizer completely failed (Peterson 1996). However, using too much fertilizer retarded succession of native vegetation because the planted grasses lived longer (McKendrick 1991).

Strategies for the reclamation of oil spills on and near gravel pad sites were burning contaminated peat and tilling to allow for volatilization (Peterson 1996). Burning contaminated soil showed the best results if it was burned right away, before the oil had time to seep into the deeper layers. The disadvantages of burning were that it sterilized the soils and decreased organic soil matter (Peterson 1996). Burning in the winter months allowed a higher plant survival (Peterson 1996). Tilling proved more effective when the contaminated area was left for a while before tilling to allow for more volatilization (Peterson 1996).

4.4.2 Restoration of cutover peatlands

During the last 10 years the Peatland Ecology Research Group has developed restoration practices for restoring cutover peatlands (Rochefort et al. 2003). This research has been focused on bog restoration, but some projects have applied this technique to the restoration of poor and moderate-rich fens (Cobbaert et al. 2004; Graf & Rochefort 2008). These research techniques should be useful to restoring wetlands affected by energy sector disturbances because the problems created by both disturbances are similar (Table 4). The main difference between the two types of disturbance is that peat extraction affects the entire peatland, while energy sector disturbances are smaller in scale. The restoration technique developed for cutaway peatlands consists of six steps.

First, the site is prepared by removing the crust because a fresh peat surface allows for a better contact between the newly reintroduced plant diaspores (Figure 8.a) (Rochefort & Lode 2006). The second step is to choose the donor site and collect the donor material (Figure 8.b). Sites which contain *Sphagnum* from the Acutifolia family for the bog restoration, *Sphagnum centrale*, *S. warnstorfii*, and *S. fallax*, *Aulacomnium palustre* and *Polytrichum strictum* for moderate-rich and poor fen restoration and *Scorpidium cossonii* and *Campylium stallatum* for extreme-rich fen restoration should be chosen as these moss species regenerate well on bare peat (Campeau & Rochefort 1996; Mälson & Rydin 2007; Graf & Rochefort *in press*). The plant material is collected in a 1:10 donor to restoration site ratio, meaning that one hectare of donor material is needed to restore 10 hectares of peatland (Rochefort et al. 2003). The top 5-10 cm of surface vegetation is collected from the donor site while the peatland is frozen to avoid damaging the donor site (Rochefort et al. 2003).

The third step in the Canadian approach to peatland restoration is to spread the diaspores using a standard box manure spreader (Figure 8.c). The fourth step is covering the diaspores with a straw mulch layer to protect them from desiccation while they regenerate. The fifth step is the optional application of a light dose of phosphorus fertilization. It has been shown that this helps the establishment of companion species such as *Carex* sp. and pioneer moss species, such as *Polytrichum strictum* (Groeneveld et al. 2007; Graf & Rochefort 2008). The last step is blocking the drainage canals to keep the water within the restoration site and improve the distribution of water (Rochefort & Lode 2006). This method costs approximately $CAN 1000 per hectare and, because it uses machinery to collect and spread the vegetation material, is practical for large restoration sites.

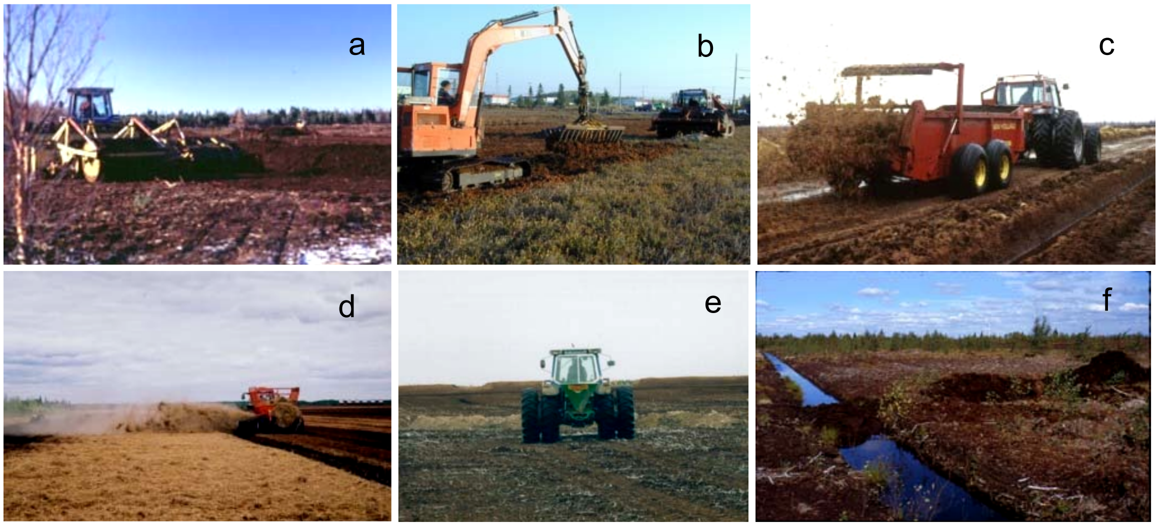

Figure 8: The six main mechanical steps for the Canadian approach to restore milled harvested peatlands. (Photos taken by Peatland Ecology Research Group).

Cagampan and Waddington (2008a; 2008b) describe a new technique for restoring cutover peatlands called acrotelm transplanting. Instead of shredding acrotelm and spreading it on the restoration site in a 1:10 donor: recipient ratio, the acrotelm is removed in large sections *circa* 30 cm deep and is placed directly on restoration site in a 1:1 ratio. The advantage to using this technique is that the acrotelm is not damaged and the restoration site will return to a Carbon accumulating system more quickly (Cagampan and Waddington 2008a). Due to the relative small size wetland disturbance created by oil, gas and in situ oil sands development, this technique would be interesting to test.

The only other existing research on peatland restoration in North America is a study that was carried out on cutaway fens in the Rocky Mountains of Colorado (Cooper & MacDonald 2000). In this study, different reintroduction techniques for vascular plants, such as seed sowing and the transplantation of seedlings, rhizomes and willow cuttings, were tested. A much higher establishment rate was seen for rhizomes and seedlings than for seeds. The lowest germination rates were seen for the *Carex* species (Cooper & MacDonald 2000). The estimated cost for this vegetation reintroduction method is between 7000 $US and 12000 $US per hectare (David Cooper, personal communication). Due to the high cost, this technique should be limited to recalcitrant species that do not respond to less expensive vegetation reintroduction techniques.

Table 4: A comparison of two types of disturbance that affect boreal wetlands. Can the techniques developed to restore cutover peatlands be used to restore peatland which have been affected by energy sector disturbances?

Disturbance	Peat extraction	Construction of seismic lines, pipelines, roads and well pads
Problems	Extensively drained Drainage ditches are placed every 30 m across the peatland. Compaction Tractors are continually driven across the peatland No seed bank	Local drainage altered Surface and subsurface water flow is impeded (by roads and pipelines) Local compaction No seed bank (roads and well pads) Possible soil and water contaminated by hydrocarbons or mineral soil (pipelines, roads and well pads)
Size of disturbance	Large (up to 300 ha)	Small • Well pads circa: 1-10 ha • Linear disturbances: 6-30 m wide and several km long
Duration of disturbance	20-40 years	10-50 years
Short term restoration/ remediation goals	Vegetation layer dominated by bryophytes Diplotelmic hydrology	Equivalent land capability. Can be restored as: • Wetland • Agricultural Land • Forested Land
Long term goal of restoration/ remediation	Return of the ecosystem's peat accumulating function	Return of the ecosystem's peat accumulating function

4.5 Experimental field trials

Although a few companies contacted had experimented with restoring decommissioned well pads through partial or complete cap removals, only one company, Imperial Oil Resources, had a report that described the wetland reclamation trial. In this project, four factors were used to asses a facility's impact on the wetland: the facility age, the facility size, the presence/absence of a filter fabric below the facility, and whether topsoil was salvaged prior to construction (Imperial Oil Resources 2006).

The goal of this field trial was to provide a benchmark for future reclamation of facilities in wetlands (Imperial Oil Resources 2006). The chosen site for this field trial is 1.15 ha in size with an average of 148 cm residual peat (Imperial Oil Resources 2008). The site was constructed within an area occupied primarily by a treed rich fen. More than 94% of the area developed in constructing the site was of this land type. (Imperial Oil Resources 2008). Partial removal and re-contouring of the fill material was initiated in 2008 and completed in late 2009. Hydrology, water quality, soil, vegetation, and amphibians will be monitored for several years afterwards (Imperial Oil Resources 2008).

This project is taking the essential first step in the experimental development of restoration techniques for a disturbed system. Imperial Oil is attempting to re-establish suitable hydrologic conditions, which is a critical factor re-establishing a wetland system, and observing to what extent nature will restore the rest.

4.6 Current practices

Currently, in order to receive a reclamation certificate, oil companies must assess and remediate contaminated soil and groundwater, reestablish drainage, re-contour and revegetate disturbed soils. The Alberta government historically has not required that former wetlands be restored back to wetlands (Alberta Environment 1995), but a recent update to the wellsite reclamation criteria now considers leaving pads in place a change of landuse and thereby requires restoration of wetland function and processes in order for a site to be considered reclaimed as a wetland (ASRD 2007). The standard practice is to leave the mineral or clay material used in well pad and road construction in place and to revegetate these areas as upland sites (Opti Canada and Nexen 2006, N. Pelletier (Devon Canada), J. Agate (CNRL), S. Willetts (ConocoPhillips), personal communication). These areas are revegetated with either 1) an upland grass mixture, 2) upland trees, or 3) natural regeneration of upland species. Such practices result in the reclamation of the site, not restoration of the ecosystem (Figure 7).

5. Conclusions

Member companies of the Canadian *Sphagnum* Peat Moss Association have been proactive in restoring wetlands. Although provinces (except for New Brunswick) do not require cutover peatlands to be restored after peat mining, many peat moss companies voluntarily restore them. After witnessing public outcry over management practices of Britain's last peatlands, Canadian peat moss companies organized a workshop, inviting scientists and representatives from provincial governments (Rochefort 2000). During this two-day workshop, an after-use policy was created for peatland. The primary after-use objective was the return of bog or natural wetland habitat through natural succession (Rochefort 2000). This was the beginning of an on-going dialog between researchers and industry, which has been sustained by annual workshops. Researchers contribute their expertise in their specific fields, while the industry helps with the practical knowledge of equipment and implementation.

Techniques developed to restore cutaway peatlands are highly pertinent to the restoration of wetlands affected by energy sector disturbances. Environmental conditions of cutover peatlands are in many ways more harsh than the environmental conditions of wetlands affected by energy sector disturbances (see table 4). Peat extraction leaves large flat expanses (up to 300 ha.) of drained, compacted peat with no plant propagules (Poulin et al. 2005). While energy sector disturbances also create areas with altered drainage, compacted surfaces, and are void of vegetation, the surrounding wetlands are left intact. If the restoration of cutover peatlands is possible, peatlands affected by energy sector disturbances should also be restorable, but many questions remain.

If restoration is a viable option, then proper stewardship dictates that restoration be done rather than wide-spread reclamation of wetlands to upland sites. Peatlands are extremely important ecosystems globally due to their ability to sequester carbon and regulate the water cycle. Reclaiming these areas to upland ecosystems will not restore their peat-accumulating or hydrologic function. Additionally, linear disturbances can result in fragmented landscapes leading to isolated habitat islands, changes in species migration, and undesirable edge effects (Forest 2001). Restoring these areas to their original ecosystems would abate the negative impacts of fragmentation and therefore merits further investigation.

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Appendices

Appendix A Databases, key words, and range of years searched.

Scientific article databases

- Web of Science (1970-present): Covers over 10,000 journals in the sciences, social sciences, and arts and humanities, as well as international proceedings coverage for over 120,000 conferences. Keywords: Wetland and pipeline, wetland and roads, marsh/fen/swamp/bog/marsh and road, and disturbance; disturbance and wetlands, and groundwater; wetland and disturbance, and oil sands; biogeochemistry and wetland; wetland and restoration, and oil; best management practices and wetland; industrial activities and wetland.
- Biosis (1970-present): A life sciences reference database that combines the journal reference content from biological abstracts with the references to meetings, reviews, books, and monographs. Updated weekly, it covers fields such as Biology, Biochemistry, Biotechnology, Botany, Zoology, and Agricultural Sciences. Formats indexed journal articles, conference proceedings, and reports. Keywords: Wetland and restoration; bog and restoration; fen and restoration; effect and wetland, and pipeline; effect and wetland, and road; effect and wetland, and seismic lines; effect and wetland, and well pads; peat compaction; oil sands remediation; oil and gas, and remediation.

Grey literature database

- Grey source (1970-present): A search engine which provides examples of grey literature, such as information produced on all levels of government, academics, business and industry in electronic and print formats not controlled by commercial publishing. Keywords: Well pad and wetlands, and restoration; Oil/gas and development, and wetlands; best management practices and wetlands; best management practices and peat; decommission and road; peat and compaction; peat and roads; peatland and restoration; peatland and road.

Appendix B People and organisms contacted

Oil and gas companies

- **Canadian Natural Resources Ltd.**
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Alberta governmental agencies

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- **Orphan Well Association**
  Alison Wolfe 403-297-8131

Environmental Consulting Firms

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- KB Prairie Consulting, 780-417-5048
- Sharp Environmental
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