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History of wetland reclamation in the Alberta oil sands

C.A. Daly *Suncor Energy Inc., Canada*

Abstract

Wetlands, mainly peatlands, cover more than half of the landscape in northeastern Alberta. Significant efforts are focused on recreating wetland ecosystems within the landscape disturbed by oil sands mining. Early wetland reclamation efforts in the oil sands focussed on constructing marshes using mining by-products, like tailings – an aqueous solution of silt, sand, clay and residual bitumen, to evaluate the potential of wetlands as water treatment systems. Some marshes developed where water collected in depressions within the reclaimed landscape ("opportunistic wetlands"). The do not contain tailings, although they may be saline if the surrounding soils are sodic. Opportunistic and oil sands process material (OSPM)-affected wetlands, those containing tailings and/or oil sands process water (OSPW), were monitored to determine whether these reclaimed water bodies functioned in a similar manner to natural wetland ecosystems in the region. Recent efforts in wetland reclamation have focused on the following: (1) improving best management practices (i.e. using bioindicators for assessment, habitat design, and revegetation strategies); (2) reclaiming wetland watersheds instead of building individual wetlands in isolation; and (3) design and construction of fen peatlands, the most common wetland type in the region. This paper summarises the history of wetland reclamation in the oil sands region, trends over time in wetland reclamation research, critical findings and the latest wetland reclamation initiatives, such as fen watershed research, design, construction and monitoring.

1 Introduction

Wetland reclamation and research programmes are abundant in the Athabasca oil sands region of northeastern Alberta where wetlands, mainly peatlands, comprise over 50% of the land base (Vitt et al., 1996). Mining activities disturb this region during open pit mining of oil sand ore containing bitumen, a heavy viscous form of oil. The mined area must be reclaimed to a state of "equivalent land capability" (OSWWG, 2000). To date, 662 km^2 of Canada's boreal forest in the oil sands region have been disturbed by oil sands mining (OSDG, 2011). Oil sands mining activities continue to increase and may ultimately disturb up to 0.1% of the total boreal forest – some 3,116 km^2 (OSDG, 2011). Given the large scale disturbance, reclamation involves reconstructing ecosystems at the landscape scale. Wetland research initiatives are critical for advising oil sands reclamation practitioners how best to design new landforms (i.e. wetland watersheds) and on best management practices (i.e. bioindicators for wetland assessment, habitat design and revegetation strategies) for re-establishing viable, productive and diverse aquatic ecosystems. The issues that challenge wetland reclamation in the oil sands centre on mitigating possible biological effects of the elevated salinity, naphthenic acids (NAs), metals and polycyclic aromatic hydrocarbons (PAHs) present in tailings and frequently used in landscape reconstruction.

Although peatlands are the dominant wetland type, marsh reclamation has been the focus until recently. Marshes are hydrologically simpler than peatlands and develop spontaneously in poorly drained sections of disturbed landscapes (Harris, 2007). In contrast, peatlands are complex systems that were deemed challenging, if not impossible, to construct since they naturally evolve over thousands of years (Clymo, 1983). Moreover, many marsh species are resistant to contaminants such as salts present in post-mined oil sands landscapes (Trites and Bayley, 2009a; Hornung and Foote, 2007). Peatland vegetation, especially mosses, is not believed to be tolerant of saline conditions (Boerner and Forman, 1975); however, fen peatlands can be dominated by sedge and shrub vegetation and accumulate carbon (peat) (Trites and Bayley, 2009b). Marshes fulfil many of the same environmental functions as peatlands, i.e. improve water quality, control flooding, and provide habitat (Mitsch et al., 2009). However, if fens were systematically replaced by marshes in the post-mined landscape, there may be a loss of habitat for diverse biota, i.e. amphibians (Mazzerolle, 1999), birds (Lachance et al., 2005), moose (*Alces alces*), caribou (*Rangifer tarandus*) (Berg, 1992), unique plants (*Sarracenia purpurea*) (Johnson et al., 1995) and rare plants (i.e. *Liparis loeselii, Cardamine dentata*) (Golder Associates, 2010; Griffiths, 2007).

This paper outlines the past, present and emerging initiatives in oil sands wetland reclamation.

2 Early wetland reclamation (1980s to mid 2000s)

Results from early laboratory work indicated the potential for tailings ponds to be reclaimed using natural processes of biological colonisation and microbial degradation (Nix, 1980a,b). A need to confirm this theory using field-scale models resulted in the construction of a series of small, shallow test ponds and pilot wetlands, marshes and shallow open water wetlands (hereafter referred to as marshes). Examples include the Syncrude Canada Ltd. (Syncrude) Test Ponds (1989–1993), Suncor Energy Inc. (Suncor) Experimental Trenches (1991), Suncor Sustainability Ponds (1991/1992), Syncrude U-Shaped Cell (1992), Syncrude Demonstration Pond (1993), Syncrude Consolidated Tailings Pond (2000) and the Suncor Consolidated Tailings (CT) Wetlands Demonstration Project (1999/2000). These programmes focused on demonstrating the capability of test ponds to store and transform tailings pond waste into benign materials housed within environmentally acceptable ecosystems. Soil and water chemistry, and biological and toxicological responses were examined over time (Gulley, 1993; Nix et al., 1993; Bishay, 1998; Bendell-Young et al., 2000). The assessment of wetlands spontaneously developing in disturbed landscapes, and referred to as opportunistic wetlands (Nix 1980a; Nix 1980b), began in 1990 at Suncor's "Natural Wetland". Gulley (1993) examined the capability of opportunistic wetlands as waste water treatment systems and sustainable ecosystems.

Field studies indicated the potential for wetlands to reduce contaminant loads, i.e. P, ammonia, As, Cu, Fe, Ni and hydrocarbons, which exceeded regulatory guidelines and were present in oil sands process water (OSPW), with short residence times <30 days) (Bishay, 1998; Daly and Ciborowski, 2008; Gulley, 1993). Conversely, longer residence times (i.e. months to years) are required to reduce toxicity associated with NAs in OSPW (Toor et al., 2007; Videla et al., 2009).

Ecological assessment of reclaimed wetlands initially focussed on phytoplankton (Leung et al., 2001, 2003; Hayes, 2005), aquatic invertebrates (Barr, 2009; Ganshorn, 2002; Leonhardt, 2003; Whelly, 1999), vegetation and avian communities (Gulley, 1980, 1982). Programmes compared revegetation techniques (i.e. natural colonisation and transplants) (Golder Associates, 2005) and examined the effects of OSPW and tailings on plant productivity, vigour, survival, and diversity (Bishay, 1998; Cooper, 2004; Golder, 2005). This work would become the knowledge base for the carbon flow, food web dynamics and reclamation strategies in Athabasca Oil Sands Wetlands (Ciborowski et al., 2011) and other wetland reclamation programmes that are currently contributing significantly to improve understanding of better wetland reclamation practices (see Section 3.2).

3 Current state-of-knowledge

Recent research programmes addressing oil sands wetland reclamation are focused on developing reclamation strategies, monitoring and design tools and improving fundamental knowledge on marsh and shallow open water wetland reclamation. Current trends in vegetation, wetland food webs and performance indicators are reviewed.

3.1 Vegetation

Landscape diversity appears reduced in oil sands reclaimed marshes compared to marshes around boreal Alberta (Crowe, 1999; Trites and Bayley, 2009a). Speculation suggests that low diversity may result from reduced local diversity compared to the greater boreal within Alberta, reduced dispersal opportunities, the young age of reclaimed marshes or constituents within oil sands process material (OSPM) (Cooper 2004; Roy and Foote, 2011; Trites and Bayley, 2009a). Dispersal opportunities by water and animals are limited since reclaimed marshes are not connected to off-site and natural water bodies (Trites and Bayley, 2009a).

Transplants may be appropriate techniques for increasing vegetation diversity within newly reclaimed marshes. Pre-mined marshes were predominantly freshwater systems. Oil sands reclaimed marshes are mainly saline because their surrounding watersheds were constructed with OSPM or covered with saline sodic overburden. Natural saline wetlands are present in the region (Trites and Bayley, 2009a); however, isolation of OSPM-affected marshes on disturbed mining sites from such seed sources may limit natural colonisation by saline-tolerant macrophytes and, consequently, development of communities and habitat structure comparable to the reference marshes. The use of vegetated soil plugs, especially from saline donor sites, appears to be especially effective for increasing species richness in marshes containing OSPM (Golder Associates, 2011). Furthermore, early planting of appropriate desired species may limit or prevent the establishment of potentially dominant, less desirable species (Noon, 1996; Aronson and Galatowitsch, 2008). Variability in water depth in newly constructed marshes negatively impact developing vegetation communities and needs to be controlled (Golder Associates, 2005; Golder, 2011).

Once established, vegetation contributes biomass and litterfall to wetland sediments, thereby increasing organic matter, nutrients and increasing water content (Trites and Bayley, 2009a; Raab, 2010). Peat soil amendments over tailings accelerate emergent plant establishment, but not submergent vegetation, compared to tailings substrate (Ciborowski et al., 2011; Cooper, 2004; Golder, 2011) and should be considered as an appropriate marsh sediment amendment. Better reclamation planning should include wet-meadow zones, which contain diverse vegetation communities, since they are currently lacking in reclaimed marsh watersheds (Roy and Foote, 2011; Raab, 2010).

3.2 Wetland food webs

CFRAW is tracking carbon flow through food webs, developing a better understanding of the effects of OSPM on the biological community, predicting changes and recommending reclamation strategies for the Athabasca oil sands reclaimed marshes. Ciborowski et al. (2011) indicated that structural habitat within marshes determines taxa presence and accumulation rates. Young reclaimed marshes containing OSPM reduce vegetation, zoobenthos, amphibian and avian richness, however, richness becomes similar to reference marshes in less than 15 years, possibly as NA toxicity is reduced and habitat structure develops. Bioaccumulation of NA and PAHs is not evident (Ciborowski et al., 2011; Ganshorn, 2002; Wayland et al., 2008). Productivity in OSPM-affected marshes is sufficient to support top predators (Ciborowski et al., 2011; Kovalenko et al., 2010), given suitable weather conditions (Gentes et al., 2006).

Salinity appears to limit diversity, production and slows succession in reclaimed marshes containing OSPM (Ciborowski et al., 2011). Non-OSPM affected marshes, those that developed spontaneously in depressions in the reclaimed landscape and receive fresh ground and surface waters, are more productive and diverse compared to those marshes containing OSPM (Ciborowski et al., 2011).

3.3 Performance indicators

A wetland performance indicators programme is developing a list of bioindicators to assess reclaimed marsh performance (Raab, 2010; Rooney and Bayley, 2010). Raab (2010) compared 45 boreal marshes, both natural and reclaimed, and developed a Vegetation-based Index of Biological Integrity (vIBI) to assess the ecological health of oil sands reclaimed marshes. Six of the twenty reclaimed marshes were identified in fair to good health and within the range of natural wetlands suggesting that some of these young reclaimed marshes are developing into ecosystems comparable to natural marshes. The vIBI needs to be tested against an independent set of reclaimed marshes to validate its capability to predict disturbance scores. However, reclamation of marshes is still in its infancy and it may take several years before such sites become available to validate the developed tool (Raab, 2010) and assess whether reclamation targets are being met.

4 New directions

Ongoing work is focussing on Pilot End Pit Lakes (EPL) as treatment systems, development of a regional natural wetland monitoring programme, improving habitat design and vegetation practices and accelerating the development of fen peatlands in the oil sands reclaimed landscape.

4.1 End pit lakes

Early water treatment research evolved into the recent development of Pilot EPL programmes. EPLs are engineered water bodies planned for development in post-mining pits that will contain oil sands by-products (i.e. tailings), receive freshwater from surrounding reclaimed landscapes and function as large scale treatment systems. EPLs are planned on numerous oil sands operators' leases. A pilot, Base Mine Lake, is currently under development at Syncrude.

4.2 Regional natural wetland monitoring programme

A regional natural wetland monitoring programme is under development through the Aquatic Subgroup (ASG) of the Cumulative Environmental Management Association (CEMA) Reclamation Working Group (RWG) in order to: (1) better understand the range of natural variability within wetlands; and (2) examine the potential effect of dewatering and mine development on natural wetland communities. The regional programme may be implemented as early as 2012.

4.3 Habitat and watershed design

Marsh reclamation design has evolved since the 1990s when marshes were constructed experimentally as test pits containing OSPM and OSPW. Recent marsh reclamation programmes have incorporated surrounding watersheds and hydrogeological modelling to produce systems that ideally are capable of generating sustainable freshwater sources and nutrient supplies (Daly et al., 2010; Price et al., 2010; Wytrykush, 2010). Examples include Syncrude's Peat Pond, Suncor's Wapisiw Wetland, the Suncor Pilot Fen Peatland and the Syncrude Sandhill Fen Peatland.

In 2010, Suncor introduced new aquatic habitat features on Wapisiw Lookout, the first tailings pond to be reclaimed in the Alberta oil sands (Daly et al., 2010). Floating vegetated logs are typically present in natural marshes and beaver ponds in the region and may act as effective perching sites for birds, amphibians, and mammals (i.e. muskrat [*Ondatra zibethicus*]). Vegetated logs were deployed on a newly constructed marsh, Wapisiw Wetland, within the Wapisiw Lookout watershed. Nesting boxes have successfully creating habitat for Tree Swallows (*Tachycineta bicolour)* in newly developing reclamation areas *(*Harms et al., 2010) where suitable nesting locations (i.e. hollows in mature trees) may be initially lacking. Cavity nesting duck boxes and bat boxes were erected surrounding Wapisiw Wetland. Evidence indicates that some reclamation areas are providing habitat and being used by several bat species (Order: Chiroptera) (Golder Associates, 2010). These structures will be evaluated for their effectiveness as wildlife attractants.

CEMA is working to develop habitat models for species of interest and management support tools for the creation of wetland habitat in the oil sands region (Eaton and Fisher, 2011).

4.4 Vegetation

To date, revegetation strategies in oil sands reclamation have primarily focussed on upland forest ecosystems. Some experimental work has examined wetland vegetation transplants and natural colonisation (Golder Associates, 2005, 2011). Recently, efforts have focused on providing guidance around riparian ecosystem, the areas bordering on streams, lakes and wetlands, establishment. GDC (2009) produced a *Riparian Classification and Reclamation Guide* which provides a classification for riparian ecosystems that can be used to reclaim and revegetate areas disturbed by oil sands mining. It was developed for landscape design support, revegetation planning and vegetation community assessment in reclaimed riparian areas. The document is under peer review by CEMA as a potential reclamation guidance document. Furthermore, the guide is undergoing field evaluation. Recommended riparian species were planted in a reclaimed marshes and development will be tracked against a reference ecosystems in order to determine whether reclaimed riparian vegetation communities are developing into an integrated, self-sustaining ecosystem functionally equivalent to natural riparian areas (Daly et al., 2010). Furthermore, the effects of soil type (peat-mineral soil versus forest floor soil) and planting strategy (hand planted versus natural colonisation) are contrasted in order to determine optimal planting practices for reclaimed riparian areas.

Ratroot (*Acorus americanus*) has been identified as a critical plant for Aboriginals Peoples because it is one of the most widely and frequently used herbal medicines in the region (Johnson et al., 1995). Laboratory experiments are characterising the effect of pH, nutrient and salinity on *A. americanus* to determine the tolerance of this critical plant in a range of oil sands reclaimed marshes (Calvo-Polanco et al., 2011). Field and greenhouse studies are characterising *A americanus* natural habitat, examining propagation techniques, i.e. seed versus vegetative propagation, and investigating establishment techniques in oil sands reclaimed marshes (Smreciu, 2011).

Peatland revegetation programmes have developed in order to identify appropriate vegetation targets and application techniques for the pilot fen peatland construction programmes at Suncor (Andersen, 2010; Emond et al., 2010; Rezanezhad et al., 2011) and Syncrude (Bloise and Vitt 2011) (Section 4.5).

4.5 Peatland reclamation

Organic matter accumulation has already been demonstrated as possible in post-reclamation oil sands marshes (Trites and Bayley, 2009b) suggesting that marshes may develop into peatlands over time. In order to speed up their development in the reclaimed landscape, recent efforts have focused on fen peatland construction in the post-mined landscape.

A study by Price et al. (2010) challenged the concept that peatland construction may be impossible and offered a conceptual model (fen model) to replace fen peatlands removed by mining with salvaged fen peat materials supported by groundwater inflow from a constructed watershed. Moving from concept to design began with establishing programme goals and objectives. For a detailed programme review see Daly et al. (2011). Briefly, the Suncor Pilot Fen Program commenced in 2008 in order to validate fen model recommendations and to meet terms and conditions of section 6.1.66 of AEPEA approval No. 94-02-00. The goal of the programme is to establish the hydrology necessary to maintain fen plant communities in a constructed fen. The objectives of the programme are to construct a fen that is (1) a self-sustaining ecosystem; (2) capable of accumulating carbon; (3) capable of supporting a variety of habitats and typical fen species; and (4) enables techniques for future fen creation to be tested and refined. The programme was divided into 5 parts: (1) site investigation; (2) watershed design: (3) vegetation strategies; (4) construction; and (5) research and monitoring.

4.5.1 Site selection and watershed design

After an appropriate location was selected, based on criteria defined *a priori*, a detailed site-specific hydrogeological study was initiated at the construction location. BGC Engineering Inc. and O'Kane Consultants Inc. modified the fen model and developed the Suncor Pilot Fen watershed designs to meet site-specific conditions (Figure 1).

The watershed itself covers 32.1 ha. It contains an upland aquifer system composed of tailings and designed to supply groundwater and surface runoff to the 2 m thickness of fen peat placed at the base of the system. A geosynthetic clay liner underneath the fen and upland regions of the watershed was designed to sustain water within this perched fen. Additional runoff may become available from adjacent slopes, i.e. east slope, western slope, south east corner and natural area (Figure 1). Excess water in the fen flows over an adjustable weir into an outlet pond that is directed northward via an engineered stream channel to a containment pond designed to contain OSPW water within Suncor's lease. A small (0.2 ha) perched fen with 0.3 m deep fen peat will be placed over tailings sand in the upland area adjacent to a hummock at a 1:1 hummock area to fen area ratio. This small scale study within the fen watershed will examine whether perched fens can develop over sand within a small watershed in a similar manner to the natural perched fens inherent in the region (Devito et al., 2011). A berm delineates the watershed and protects the reclamation area from nearby operations.

4.5.2 Vegetation strategies

A research programme was initiated to investigate the effects of tailings on typical fen plants and to better understand how compounds (i.e. NA and salts) in OSPW are transported through fen mesocosms (Andersen, 2010; Emond et al., 2010; Pouliot and Rochefort, 2011; Rezanezhad et al., 2011). Laboratory and greenhouse fen mesocosm studies have revealed that fen graminoid plants (*Calamagrostis stricta*, *Carex atherodes*, *Carex aquatilis*, *Carex utriculata*, *Trichophorum cespitosum*, and *Triglochin maritime)* native to the Athabasca oil sands region are capable of tolerating elevated concentrations of sodium (Na) salts (~385 mg l^{-1}) and NAs (~40 mg l^{-1}) present in OSPW and suitable for growing in the Suncor Pilot will containing a tailings-constructed aquifer (Rezanezhad et al., 2011; Daly et al., 2011). However, mosses (*Bryum pseudotriquetrum, Campylium stellatum, Sphagnum warnstorfii* and *Tomenthypnum nitens)* appeared to have a lower tolerance threshold to OSPW, especially under drier conditions when water was derived by capillary from OSPW (Pouliot and Rochefort, in press). Knowledge from this study was incorporated into the fen watershed design and revegetation plans.

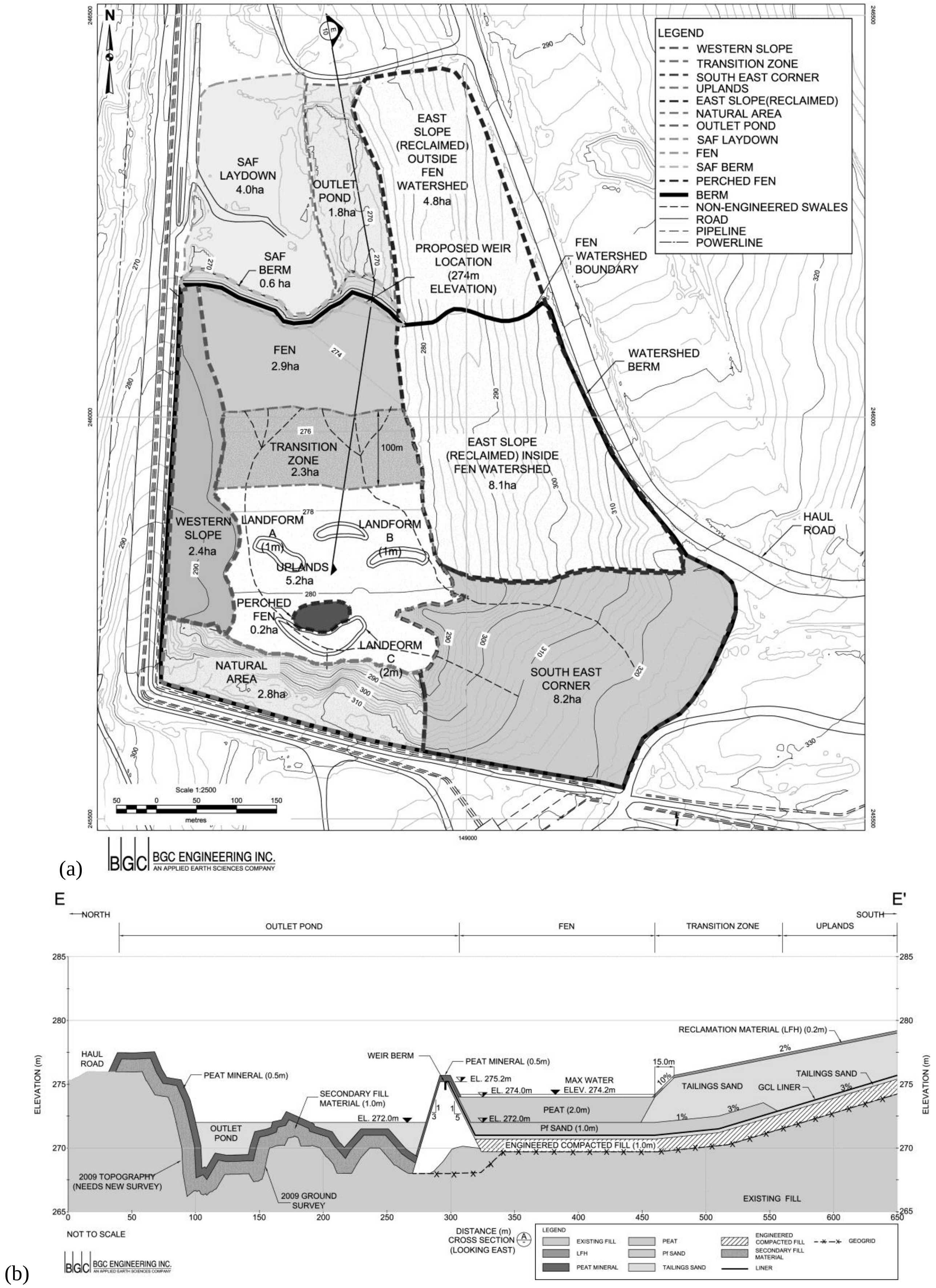

Figure 1 (a) Plan view and (b) cross-section of the Pilot Suncor Fen watershed conceptual-level designs

Although poor water quality may occur shortly after fen watershed construction due to the presence of salt ions and some organics, i.e. NAs, water quality is expected to improve over time as rainwater flushes the tailings sand aquifer with fresh water. Consequently, many salt tolerant species were selected for revegetating the constructed fen. However, it will likely evolve into a freshwater system over time.

Target plant communities for the Suncor Pilot Fen were selected according to the following criteria: (1) moderate-to-extreme rich fen plant; (2) shrub, sedge, grass, forb or moss species; (3) shows some sign of saline tolerance; (4) good peat accumulator; and (5) present in local fens. Selected species met most, if not all of the above criteria. A few other peatland species were added to the target species list that did not comply with the majority of the criteria, however, they were included for their ecological or cultural significance (e.g. *Oxycoccus microcarpus*) in the region.

Four vegetation strategies will be tested in the Suncor Pilot Fen to determine the optimal strategy for vegetating oil sands constructed fens. The strategies are as follows: (1) moss transfer (Rochefort et al., 2003); (2) seedlings plantation; (3) direct seeding; and (4) the control or spontaneous revegetation, i.e. seedbank within the fen peat; aerial seed rain.

4.5.3 Research and monitoring

Research and monitoring of the Suncor Pilot Fen is a critical step for the successful development of fen peatlands because it will determine success according to the programme's goals of creating a self-sustaining ecosystem that is carbon accumulating, and capable of supporting a typical fen plant community. Furthermore, understanding design implications and development of more optimal designs is a crucial step for the successful development of fen peatlands in oil sands reclamation.

A five-year integrated hydrological, biogeochemical and ecological research programme was developed by Dr Jonathan Price (University of Waterloo), in collaboration with Drs David Cooper (Colorado State University), Rich Petrone (Wilfrid Laurier University), and Maria Strack (University of Calgary). The programme will examine hydrology, water quality, revegetation, carbon dynamics, plant establishment success, and microbial communities in the constructed fen and in nearby reference fens. It is funded by the Canadian Oil Sands Network for Research and Development Environmental Reclamation and Research Group (CONRAD ERRG). Additionally, wildlife monitoring cameras will examine whether wildlife are recolonising the area after fen peatland reclamation is complete.

5 Conclusions

Wetland reclamation continues to evolve through guidance developing from reclamation research initiatives. Lessons from programmes such as the Suncor Pilot Fen are expected to shape the future of wetland reclamation in the Athabasca oil sands region.

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