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Constructing fen peatlands in post-mining oil sands landscapes: Challenges and opportunities from a hydrological perspective

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ABSTRACT

Peatland development occurs naturally over long periods of time in response to climate, geology, hydrology and vegetation. Open-pit oil sands mining activities in Northern Alberta result in large-scale removal of the surficial landscape, which comprises many (~50%) peatlands, approximately 90% of which are fens with a wide range of peat thicknesses (<1 m to ~5 m). Recently, the concept of peatland creation was adapted into the regulatory framework. Two experimental fen peatlands have now been constructed on post-mining landscapes in order to test the design implications and implementation methods and to develop knowledge to advance the concept. These two systems were guided by different conceptual approaches: one utilized numerical modelling for landscape optimization, while the other attempted to mimic the landscape position of natural fen systems (and supported the design with numerical modelling). Both system designs attempt to accelerate succession by adding peat substrate (0.5 m and 2 m) and revegetating, with the belief that the system will stabilize within decades as opposed to millennia. This paper provides an overview of the feasibility of peatland creation, from a primarily hydrologic perspective, and addresses the complexity of determining whether these projects can be deemed a success.

Future landscape design plans could benefit from a change of perception of the role of peatlands in the landscape. This change should involve a shift away from viewing wetlands as landforms constrained to low-lying areas within the reclaimed landscape, and towards recognizing that peatlands can function as both a sink and source of water to the remainder of the catchment. Wetland interconnectivity within the reconstructed landscape could increase water detention and storage during wet periods, which would benefit both the wetlands and the forestlands during dry periods. The assessment of the success of these constructed systems should be a reflection of our ability to correctly and accurately predict the influence of external forcings (e.g., climate) on the processes operating within a newly constructed system. Short timeframes (~5 years) are sufficient to characterize a range of processes operating in the constructed ecosystems; however, longer time periods will reduce uncertainty in the assessment of the system's successional pathway. The design of future constructed fen peatlands must employ an adaptive approach that assimilates the knowledge developed in the current research and the information attained over the longer-term to guide the design of future fen systems.

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1. Introduction

In the Athabasca Oil Sands Region (AOSR) in Northern Alberta, Canada, mine closure and reclamation designs aim to return landscapes to functioning ecosystems following surface mining of oil sands deposits. Peatland creation is a new concept, not attempted prior to the construction of the two fundamentally different fens, and their associated watersheds, on post-mined oil sands leases that are discussed in this paper. The Nikanotee Fen and watershed was based on landscape optimization through numerical modelling of an isolated upland-fen system. It was constructed within the Millennium mine lease at Suncor Energy Inc. oil sands mining operations site. The Sandhill Fen and watershed was designed to mimic the landscape position of regional, connected natural fen systems with the design being tested with numerical modelling of groundwater interactions with adjacent landscapes. It was constructed on Syncrude Canada Limited's Mildred Lake lease. Both systems are located approximately 40 km north of Fort McMurray, Alberta. The Nikanotee Fen was constructed on an overburden dump (Daly et al., 2012), whereas the Sandhill Fen was constructed on a sand-capped composite tailings (a slurry of tailings sand and fine tailings with gypsum) deposit (Pollard et al., 2012). The unique features of each system and the implications for ecosystem function are described within this paper.

Although natural peatlands form over thousands of years (Clymo, 1983), creation of a fen peatland was considered possible if the landscape was configured to provide a hydrogeological setting that can provide the water supply necessary to sustain fen peatland functions (Devito et al., 2012; Price et al., 2010). Because it exhibits a strong control on the chemical and biotic processes operating in peatlands, hydrology is the most important process regulating wetland function and development (Mitsch and Gosselink, 2000). Generally, a basic understanding of the hydrogeological setting is required prior to developing a conceptual model and applying it to a system (Reeve et al., 2000), since both the local landscape and regional topographic position can influence system function. Similarly, an understanding of the hydrologic function, both within individual systems as well as their connectivity within the surrounding constructed system, is required for constructed landscapes. However, within these landscapes, the hydrogeological setting can be designed, modified and constructed to meet the requirements of a conceptual model. It is critical to consider the influence of climate during the development of watershed designs that include fen peatlands (Devito et al., 2005a; Devito et al., 2012), since water availability to satisfy soil water storage and to recharge groundwater is driven by the difference between precipitation (P) and actual evapotranspiration (ET) (Smerdon et al., 2008). Indeed ET rates can be controlled to an extent through soil texture, water availability, vegetation cover and microclimatic manipulations (e.g., mulch surface cover) in constructed landscapes. However, manipulation of precipitation dynamics is unrealistic. Accordingly, fen creation must be guided by the ability to design and contour the reconstructed landscape to provide a suitable hydrogeological setting for a fen peatland under regional climatic conditions at the time of construction. These designs should also incorporate future climate change scenarios, which generally show a gradual warming trend (IPCC, 2013) but less certainty with respect to the magnitude of the predicted increases in precipitation and evapotranspiration (IPCC, 2013; Ireson et al., 2015; Keshta et al., 2011; Thompson et al., 2015).

One of the major challenges facing fen creation and development in this setting is that of limited water availability in the sub-humid climate of the western portion of Canada's Boreal Plain ecozone (Ecological Stratification Working Group, 1995), herein referred to as the Canadian Western Boreal Plain (WBP), where P is often less than potential evapotranspiration (PET; Marshall et al., 1999), and wet periods occur with a 10 to 15 year frequency (Devito et al., 2005b). Additional challenges exist with regard to water quality in a post-mining landscape comprising a substantial proportion of oil sands tailings and saline-sodic overburden materials. In an effort to surmount these challenges, multidisciplinary teams of research scientists and engineers have developed strategies to create fen peatlands and integrate them into constructed watershed designs (Pollard et al., 2012). Despite the incorporation of water and solute management strategies designed to mitigate anticipated challenges, the performance of these constructed systems is difficult to predict due to the lack of precedent.

Analysis of the initial field-based measurements of constructed fen systems is now underway. The purpose of this commentary is to present and discuss the main issues that are central to the subject of fen creation, from a primarily hydrological perspective, in open pit post-mined oil sands environments, including results from emerging research on this subject. A brief overview of the challenges associated with water quality is also included in this paper, since this is an important aspect to consider when discussing the feasibility of integrating constructed fen ecosystems into reclaimed landscapes. Further, peatland creation requires consideration of external climatic forcings and coupled internal hydrological, ecological and biogeochemical processes. However, the focus here will be on the hydrological processes and their controlling factors. The general approach is to: 1) assess the feasibility of peatland creation in a regional (i.e., WBP) context; 2) identify the underlying principles that are incorporated into the fen creation conceptual approaches; 3) discuss the suitability of the conceptual models for implementation in an oil sands open pit mining environment; and 4) address the complexity of determining if these fen creation projects can be classified as a success or failure.

2. Suitability of regional climate

The oil sands region of Northern Alberta is within Canada's Boreal Plain ecozone (Soil Classification Working Group, 1998) where deep (20–200 m) heterogeneous glacial deposits result in a complex subsurface hydrology (Devito et al., 2005a; Devito et al., 2012; Smerdon et al., 2005) that underlies a surficial landscape mosaic of forestlands and wetlands (predominantly fen peatlands; Vitt et al., 1996). In most years, PET slightly exceeds P in the sub-humid climate of the WBP region (Bothe and Abraham, 1993; Marshall et al., 1999). The hydrology of WBP ecosystems is strongly controlled by the deep heterogeneous sediments in the upland areas and their potentially large available water storage capacity (Redding and Devito, 2008; Smerdon et al., 2005). This is a key control on the nature and magnitude of water distribution and redistribution within the landscape, thus the presence and function of wetlands (Devito et al., 2012; Devito et al., 2005b). A large proportion (>70%) of annual precipitation occurs in the summer, usually as short-