Hydrogeological Considerations for Landscape Reclamation on Soft Tailings Deposits in the Athabasca Oil Sands Region

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Closure plans for oil-sand mines must include wetlands due to their abundance in natural boreal environments. With limited knowledge available for industrial scale wetland reclamation in northern sub-humid climates, Syncrude Canada Ltd (SCL) launched multidisciplinary design and research programs to evaluate the methods and materials needed to create sustainable wetland/forestland complexes on soft tailings deposits. Due to complexities of wetland ecohydrology and challenges associated with tailings deposit reclamation, reconstructed watersheds on tailings deposits must exhibit favorable hydrologic systems to support wetland functions, while accommodating the reclamation materials available, elevated salinity of tailings, and an average annual moisture deficit associated with the region's sub-humid climate.

In 2012, SCL completed reconstruction of Sandhill Fen Watershed (SHW), a 52 ha fine-grained sand watershed built on a soft tailings deposit, to explore the feasibility of constructing landscapes that promote wetland development. The watershed is comprised of uplands, hummocks of various sizes connected by broad swales, which surround a central lowland, designed to be a wetland (Figure 1). Soil and subsoil type, thickness and placement vary across the watershed, as do upland vegetation type and density. The watershed was designed to test the conceptual model that hummocks recharge groundwater that then discharges in adjacent wetlands. The goal of developing shallow, local flow systems, instead of deeper, longer intermediate flow systems, was to flush shallow tailing materials while limiting salinization of cover materials to maintain a hydrologic system that could sustain wetland vegetation and other biota.

The purpose of this study was to characterize the hydrology of SHW using groundwater, surface water, and meteorological data from 2015 to 2017 to evaluate dominant watershed characteristics influencing water availability and quality on wetland sustainability. More specifically, the objectives of this research were to evaluate a) the short- and long-term dynamics of the shallow flow system in the watershed, b) the spatiotemporal evolution of solute concentrations, and c) the influence of the watershed's design and hydrogeological characteristics on the resulting groundwater system.

Field hydrologic data were generally collected or downloaded May through October. Manual water level, temperature and electrical conductivity measurements were taken bi-weekly from 200 piezometers and wells distributed in transects across the watershed; automated water level measurements were recorded hourly, year-round, with 60 transducers. Ground- and surface-water samples were collected annually, mid-summer. Areal distributions of standing water and saturated soil were mapped bi-weekly to monthly. Soil moisture profiles were measured in 126 access tubes bi-weekly and soil moisture and tension were logged in nine soil pits year-round. Three eddy-covariance stations collected evapotranspiration data. Daily precipitation was calculated using data from tipping buckets, and continuous depth and soil water equivalent sensors.

Hydrologic system dynamics were analyzed using maps and time-series of water tables, hydraulic heads, electrical conductivities and soil-saturation/standing-water. A three-dimensional finite-difference model was developed and calibrated to observed field conditions. Recharge distributions used in the model were obtained from a parallel study which evaluated the movement of water through the unsaturated hummocks. Scenario testing identified the dominant hydrologic processes and parameters that control sources, paths and scales of groundwater flow.

A shallow, intermediate groundwater flow system dominated by lateral flow developed within SHW (Figure 1). Water flowed from a groundwater divide located near the south boundary, through the wetland, northward and eastward, indicating all fresh water originates from recharge within the watershed. Minimal to no mounding was observed below hummocks and no surface runoff observed in swales. Shallow water tables near, and standing water in, the lowlands responded dynamically to precipitation events, compared to hummocks which showed a delayed response (Figure 2a). Shallow water table configurations responded to variable recharge rates associated with different soil and vegetation prescriptions, and water table depth. Localized areas with gradual slopes and shallow water tables were prone to elevated solute concentrations when near-saturated soils became saturated with positive water pressures immediately following precipitation events (Figure 2b). These results will help with the design of reclaimed watersheds that can sustain wetlands in post oil-sand mining landscapes.

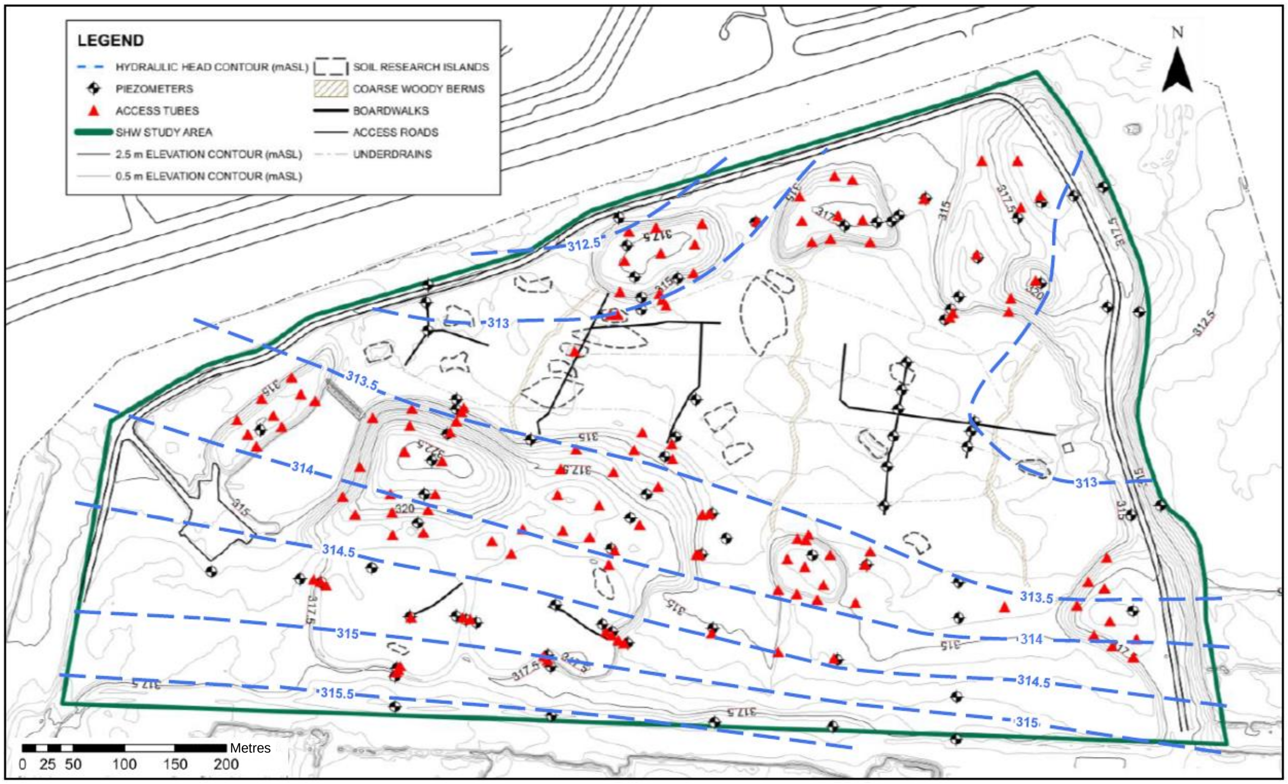

Figure 1. Topographic map of SHW with the water table configuration (blue) during summer of 2016. Map includes locations of soil moisture access tubes and piezometer nests.

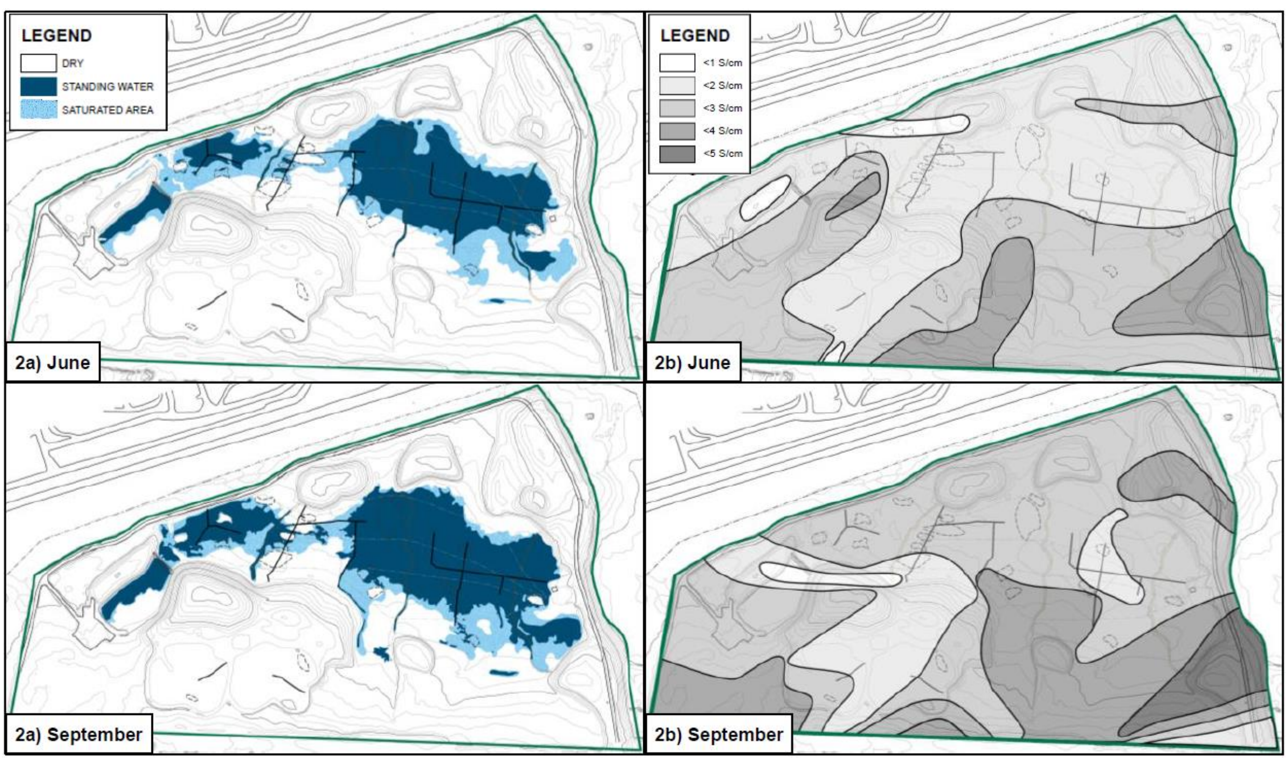

Figure 2. Spatiotemporal evolution of a) saturation and standing water, and b) electrical conductivity (EC) in SHW collected in June and September 2016. June demonstrates mid-summer dryness and fresh to moderately-fresh EC. September demonstrates increased soil saturation following a 60 mm precipitation event and increased EC at the toes of hummocks and in swales (i.e. areas with shallow water table depths). EC was measured at the water table.