Hydrological and Hydrogeological Performance of Constructed Hummocks at a Reclaimed Composite Tailings Deposit

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Summary

The land disturbance footprint of oil sands mines is appreciable in Alberta's boreal forest, necessitating large-scale reclamation. Composite tailings (CT), which are soft tailings comprised of fine- and coarse-textured wet tailings mixed with gypsum, are produced during the bitumen extraction process and become the foundation for many reclaimed landforms. To produce a trafficable surface for reclamation, CT deposits are often capped with coarser tailings or overburden materials. Reconstructed landscapes comprised of CT must be capped and designed to support the development of boreal forest ecosystems in a sub-humid climate, which necessitates proper material placement such that the subsequent hydrologic system that develops can sustain reclamation vegetation and yield water of adequate quality and quantity.

A key component of reclaimed landscapes are hummocks, which are local to intermediate scale constructed landforms that create topographic relief. Hummocks provide multiple performance functions on the reclaimed landscape, including landform drainage, management of water quantity and quality, and establishment and growth of upland vegetation. Over the past 20 years, Syncrude Canada Ltd. has reclaimed and monitored numerous hummocks on CT deposits with varying geomorphic characteristics (e.g. height, geometry, size, and grain size distribution), providing the opportunity to evaluate how a range of hummock designs influence the landscape's hydrological performance.

Hummock performance monitoring has included: groundwater level, electrical conductivity, temperature, and groundwater chemistry measurements in piezometers and wells; manually-measured profiles of soil water content; and continuously-measured profiles of soil water content, soil water pressure head, electrical conductivity and temperature. Hummock-scale monitoring has been paired with measurements of atmospheric exchanges (e.g., evapotranspiration), using

eddy-covariance stations and meteorological stations, as well as measurements of vegetation performance and growth. The available data records vary by hummock, with some locations having nearly a decade of monitoring data. These field data have been incorporated into analytical and numerical models that facilitated further interpretations by simulating how a range of potential hummock designs are linked to hydrological performance.

Field and modelling results indicate that surface runoff on hummocks may only occur during snowmelt and extreme precipitation events. As such, water exchange between hummocks and the surrounding landscape primarily occurs through shallow groundwater flow. A hummock's influence on the nearby groundwater flow pattern (i.e. groundwater mounding) is dependent on its position relative to the larger-scale groundwater flow system (i.e., CT deposit-scale flow), size (i.e., areal extent), hydraulic conductivity, and recharge rate. Hummocks occurring in landscape positions where the intermediate or regional slope (i.e., hydraulic gradient) is lower can more readily alter groundwater flow patterns. When the groundwater flow pattern is altered by a hummock, the permanence and height of the groundwater mound that forms is dependent on the timing and magnitude of recharge and the hydraulic conductivity of a hummock. When hummocks do not alter the groundwater flow pattern, the amount of recharge they facilitate still influences the water balance of the reclaimed landscape. The amount of recharge occurring is primarily dependent on hummock height, soil cover texture, and associated vegetation characteristics. Hummocks not tall enough to limit root water uptake from the saturated zone decrease recharge or result in net upward flux.

Shallow groundwater solute concentrations at hummocks are influenced by flushing rates (i.e., dilution by fresher recharge) and the interaction of hummocks with larger-scale groundwater flow. Hummocks with shallow water tables or gently-sloping hummock-lowland transition zones are prone to elevated solute concentrations, especially following precipitation events, which is likely attributable to evapoconcentration, lateral groundwater seepage, and/or groundwater ridging. Fresher shallow groundwater flow systems appear to be more readily facilitated by laterally-extensive, broader hummocks, low to moderate in height (that maintain adequate separation between the rooting zone and the water table) with steep slopes near the transition to lowlands.

These findings have important implications for landform design criteria and highlight how decisions made by reclamation managers should align with the desired or necessary function of a particular reconstructed landform and the overall watershed.