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Use of three-dimensional topography as a tool for closure integration at Syncrude Canada Ltd.'s Mildred Lake and Aurora North leases

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Abstract

Planning for closure in the mineable oil sands has evolved since the industry began in the late sixties. Throughout this evolution, Syncrude has been a leader in land reclamation, reclamation research and reclamation certification, having received the first ever reclamation certificate in the oil sands for Gateway Hill, a landform that began construction in the 1980s. Today, central to closure planning is the desire and expectation that boundaries at closure will be integrated with the adjacent land, whether another lease or with the natural environment.

Syncrude's vision for the 2011 Life of Mine Closure submission was to build a plan that is both attainable and defensible with realistic assumptions that meet the above criteria and the goal of a landscape that does not require perpetual maintenance. To meet these goals, Syncrude has undergone organisational changes and increased investment in integrated mine, tailings, reclamation and closure planning. The outcome is a process that supports opportunities for identifying challenges and optimisation through planning and testing. Central to the gains made in the integrated closure planning approach taken by Syncrude for the 2011 Life of Mine Closure submission, and the focus of this paper, is the development of a physically sound three-dimensional model of the final closure landscape for Syncrude's Mildred Lake and Aurora North leases. Two case studies are presented that illustrate the benefits of this approach that provide a foundation for the more traditional elements of closure planning.

1 Introduction

Oil sands development in the mineable portion of the Athabasca oil sands region in North-eastern Alberta evolved from a scientific curiosity in the early 1900s to a significant economic force in the world. The three oil sand deposits of Alberta, including the Athabasca, Peace River and Cold Lake deposits cover an area of 140,000 square kilometres or 14.1 million ha, of which approximately 350,000 ha are considered to be suitable for surface mining (Oil Sand Developers Group, 2009). Syncrude is a key player in reclamation and closure in the region with over 1 million ha of mineable oil sands lease holdings and forty years experience in research, development and reclamation.

Closure planning in the mineable oil sands industry has some unique challenges including scale, lease integration, cumulative effects and regulatory and stakeholder expectations. Surface mining of oil sand deposits require temporary disruption of natural landscape processes and the subsequent reconstruction of the entire landscape. The landscape reconstruction process consists of a number of sequential and iterative plans, including the soil recovery and management plan, mine and overburden management plan, ore recovery plan, tailings management plan, water management plan, and revegetation plan. Each plan is inextricably linked to the previous plan. Therefore, subtle changes in the ore recovery, mining, tailings and/or water management plans and operations can result in substantial impacts on reclamation (soil placement and revegetation) and closure.

Planning activities that have not been traditionally considered as 'reclamation' are in fact the foundation of successful reclamation and lease closure planning. The complexities of tailings management, and the ever growing regulatory and stakeholder expectations add even greater technical constraints to reclamation planning. Express integration between the plans is required in order to achieve closure goals.

Previous closure plans were presented in two dimensions (2-D) and have relied on assumptions about the actual physical nature of the landscape to support the plan. Although this was the best tool at the time, this approach did not provide a strong enough link between key closure planning steps and groups within Syncrude because there was a gap between the conceptual closure plan and the actual field operations plans. The development of three-dimensional digital elevation model (hereafter referred to as 3-D closure topography) was identified as a potential tool to provide some key benefits to the closure planning process for the following reasons:

- To improve the integration and alignment of planning elements within Syncrude, thereby increasing the credibility of the plan.
- To provide a physical representation of the closure goals that could be communicated to operations for execution.

For the 2011 closure submission, Syncrude invested in the development of a continuous 3-D closure topography model of the final closure landscape to integrate landforms and structures currently being constructed with landforms required for final reclamation. This paper outlines the benefits of the 3-D closure topographic model in closure planning and examples of its use in Mildred Lake and Aurora North closure planning.

2 Phases of closure planning

Closure planning integrates all activities that take a unit of land from natural Boreal forest to final closure landscape (Figure 1) and can be divided into two main phases of activities. The first phase focuses on the physical earth moving activities, including soil reclamation material salvage, overburden removal, ore mining, landform construction (overburden placement and tailings infilling), surface water control features (hummocks and horseshoes), inter-landform connections (swales and channels) and finally large scale soil reclamation material placement. Planning elements within Phase 1 range from the macro-scale (i.e. landform) to the meso-scale (i.e. sub-landform) and are connected in space and time.

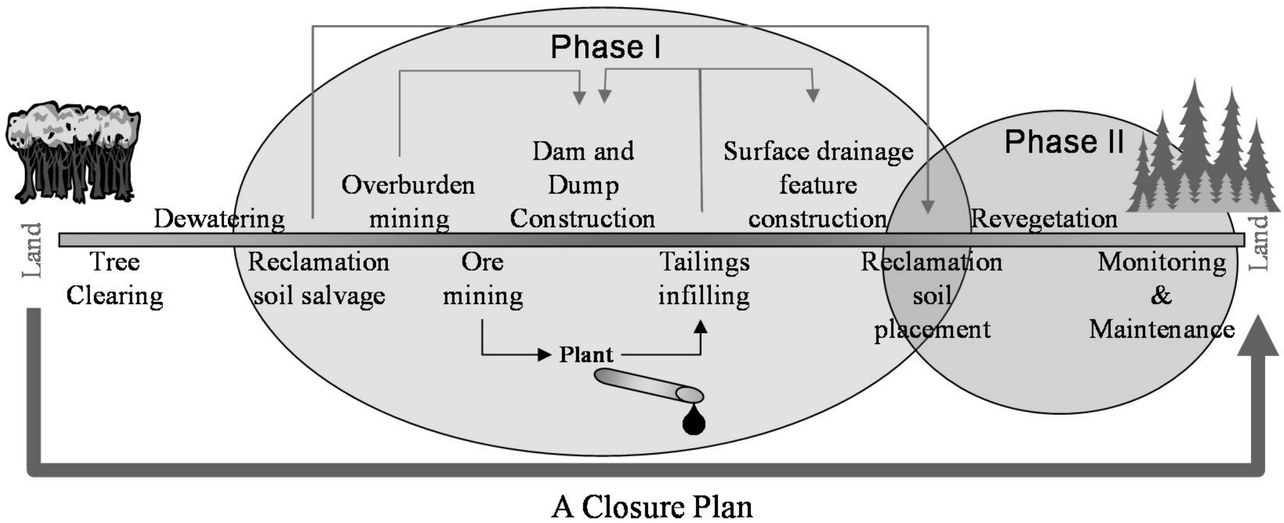

Figure 1 Schematic representation of the series of activities involved in successful closure planning

The second phase includes reclamation land capability plans, revegetation plans (forested and non-forested), and end land use modelling. These phases of planning are sequential and outcomes of later phases have the potential to influence initial phases in subsequent plan iterations. This process proceeds on an annual cycle resulting in continuous improvement of plans over time.

Phase 1 and Phase 2 planning elements can be generalised as engineering activities and ecological activities, respectively. This is not to imply that there are no ecological considerations as part of Phase 1 planning and vice versa, but that in general, engineers of various types perform Phase 1 tasks and ecologists, soil scientists, foresters, and biologists perform Phase 2 tasks. In the past, closure and reclamation planning has focussed largely on Phase 2 planning elements.

The Cumulative Environmental Management Association (CEMA) Landform Design checklist (CEMA, 2005) clearly outlines the need to address the full range of planning considerations for landscape reconstruction in the oil sands region. Watershed research on the Boreal Plain and on the several long term reconstructed watersheds research facilities at Syncrude have shown the importance of reconstructing functioning hydrologic response units, from the landform scale to sub-watershed scale to ensure success. Thus, revegetation and soil placement plans must be developed in the context of the landforms. The Phase 1 planning elements; namely the mine and tailings plans, provide the attributes, assumptions, and timing critical to supporting the credibility of subsequent plans. The largest challenge in making the closure plan achievable at every level of planning is the ability to sequence activities through time. Improved integration between plans, particularly between Phase 1 and Phase 2 elements was required for success.

Additionally, the level of detail applied to short term execution plans has to maintain focus on the final closure goals. Decisions in the field today have the ability to impact the capacity to reach closure goals or change the economics of the plan, just as decisions made on closure assumptions have the ability to impact mining and tailings operations in the field today, as discussed below in the case studies. Moreover, because planning elements are inter-connected in space and time, changes in one planning element at one point will reverberate throughout the plan. In the absence of an integrated plan, from land disturbance to closure, the impacts of change may not be adequately addressed inside isolated planning elements.

3 Phase 1 – landscape design

The goal of a closure plan is to develop an integrated landscape design that still provides enough short term flexibility to meet the mining and tailings operations business needs. The primary objectives of the mine and tailings plans are to:

- Develop economical mine plans that supply oil sand (balance of bitumen grade and fines) for extraction and upgrading.
- Design and construct geotechnically stable containment for mining by-products (solid tailings, fluid fine tailings, recycle water, and coke) with available materials (overburden and tailing sand) in accordance to licensing approvals regulated by Alberta Dam Safety.
- Ensure that there is an adequate recycle water supply to the bitumen extraction process.
- Design and construct geotechnically stable surface water control features (controls and landforms) on all deposits and structures to meet closure surface drainage designs.

Individual landform designs are developed by establishing a set of boundary conditions and assumptions including elevation constraints, volume constraints, and conceptual surface drainage plan. By reintegrating the designs into a continuous digital elevation model consistent with the underlying volumetrics the 2-D assumptions could be tested rigorously. For example, the physical alignment and integration of landforms in support of lease closure drainage and the availability of required volume of landform construction material for construction of the physical features assumed in 2-D plans. Additionally, and possibly of more value, is the communication value of the 3-D surface for integrating planning. The 3-D topography provides a real spatial representation of the closure goals for each landform that can be communicated effectively between closure planners and short range planners and operations.

Development of a continuous, volumetrically true closure topography or digital elevation model that satisfied the overall surface drainage design was identified as a potential tool for integrating Phase 1 landscape design elements. The 3-D closure topography was developed to include macro- and meso-scale design elements. Macro-scale design elements are focused on geotechnical stability, containment planning, and overall surface drainage design. The meso-scale design elements are smaller scale elements including surface water control features.

3.1 Containment planning

Prior to 1995, mining and tailings activities were independent planning functions within Syncrude because tailings were stored in out of pit settling basins which were constructed from tailings sand, providing storage for recycle water and accumulating fine tailings. Overburden, which is the non oil bearing soil that must be removed to expose the oil sand, was used for construction of large landforms (often referred to as dumps). As the out of pit tailings storage facilities reached maximum storage capacity and sufficient in-pit space was available, tailings containment opportunities were created in the mined out pits by building dykes with suitable overburden, and relying on the natural in situ walls of the pits for containment. The pit containment ponds have a maximum solids storage capacity based on final closure topography, and a maximum fluid storage capacity based on licensed geotechnical dykes, as per Alberta Dam Safety licensing and approvals.

The maximum fluid storage elevation in each pond at any point in time is dictated by the actual constructed portion of the dyke. To meet recycle water and tailings containment demands, dykes are often built in stages to allow for initial tailings storage as the mine continues to advance, uncovering footprint for the dyke and allowing construction of the dyke to final design, as depicted in Figure 2. When the ponds reach final maximum allowable fluid elevation, any subsequent tailings solids deposited into the pond will require displacement of fluids to the next available pond. This sequence repeats itself until mining reaches final pit limits and the last dyke is constructed. The maximum fluid fine tailings that can physically be stored in the end pit lake (EPL) is dictated by the total fluid storage available in the last year of mining as the operation is striving to achieve final closure topography on all the pit areas.

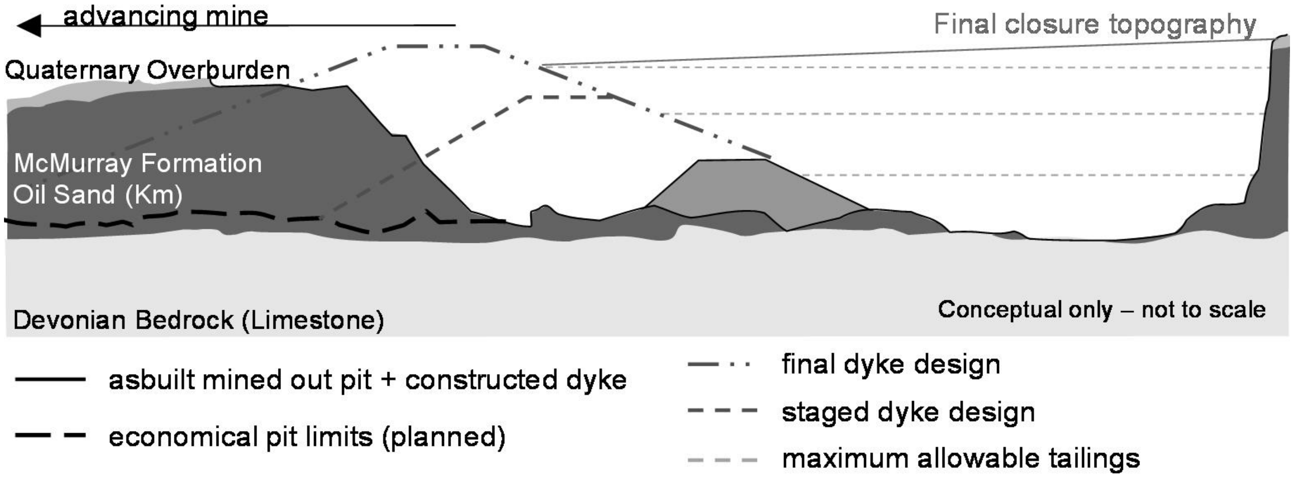

Figure 2 Schematic representation of progressive dyke construction and tailings containment

3.2 Surface drainage path

As illustrated in Figure 2, the closure constraint of the greatest influence to the mine and tailings plan (i.e. containment) is the overall lease scale closure drainage path. The initial watershed design focuses on the large-scale surficial drainage path linking all the major overburden structures and tailings facilities to a central drainage scheme to sustain EPLs and to direct surface water flow to a receiving waterbody.

The closure topography defines the total and final solid tailings space available for containment in each of the mined out pits. If the watershed design is changed, then this will impact tailings storage plans throughout the mine sequence. The major drainage path, drainage features and outlet elevations are set in this stage. Meso-topography is a mid-range scale of planning that further directs surface drainage towards the main water features and canals.

3.3 Surface water control features

Surface water control features are essential to the closure landscape to manage runoff, infiltration, and pond residence time which through design can control groundwater elevations and flow directions. Surface water control features included in the 3-D closure topography include sand hummocks, horseshoe berms and swales and dyke breaches/outlets.

3.3.1 Hummocks

Hummocks are designed to manage the groundwater table elevation in the reclamation landscape where water table control is required. Hummocks built with hydraulically placed sand are currently being constructed on Mildred Lake's East In Pit (EIP) facility and are shown on all sand based closure deposit designs. Initial pore fluids in the reclaimed landscape are saline process affected waters which need to be kept away from the active root zone of reclamation vegetation. Groundwater elevations also need to be managed in the surficial unsaturated zone to reduce likelihood of salt pan forming due to evaporation which would have a detrimental impact on vegetation years after the closure landscape has been completed. Design assumptions for hummocks are based on the design criteria for surface drainage and water-table control in Syncrude's Landform Design Guide (BGC, 2009).

3.3.2 Horseshoe berms and swales

Overburden dumps have drainage divide berms (often referred to as horseshoe berms) on the top of the structures that will direct an acceptable volume of surface water drainage to a swale (designed after Golder, 2004). The intent is to limit the accumulation of water on the structure and manage the flow to a designed element (swales) and then into main collector ditches and canals. Horseshoe berms and swales not only function as key water management features, but also support the development of diverse vegetative communities and are aesthetically pleasing.

3.3.3 Dyke breaches/outlets

There are many dam structures at each of the Mildred Lake and Aurora North leases that need to be breached to no longer be considered a fluid retaining structure in the final closure landscape. Syncrude has the expectation that dams will be successfully breached to limit any required perpetual maintenance of the reclaimed landscape. Breaches and outlets have a high-level geotechnical design with 15H:1V to 20H:1V side slopes in sand structures and 6H:1V to 8H:1V side slopes in overburden structures. These are significant projects, requiring the movement of millions of cubic metres of material that must be accounted for in the final closure topography.

4 Case studies

An example of the 2-D conceptual closure plan that was developed in 2006 for the East Pit on Mildred Lake lease is shown in Figure 3. The 2011 3-D closure landform figures are shown in Figures 4 and 5 for Aurora North and Mildred Lake, respectively. The 2011 surfaces integrate all of the Phase 1 planning elements, including geotechnical constraints, containment, overall surface drainage design and surface water control features at the macro- and meso-scales discussed above. The two case studies presented below provide details on how the development of the 3-D closure topography was beneficial in supporting landscape design at each lease.

4.1 Aurora North

At closure, the Athabasca River will be the receiving body of water for the main drainage path through the Aurora North Lease. Although previous closure plans showed the EPL at an elevation of roughly 260 metres above sea level (masl) (providing a 4% surface water gradient connection to the Athabasca River, at 230 masl) the volumetrics of material placed did not create topography upstream of the lake that produced an EPL at 260 masl.

The 2004 mining and tailings plans had over filled the East Pit and under filled the Center Pit relative to the closure topography depicted in the 2006 Closure submission. The 2007 plans had been developed with shorter term mining and tailings mass and volume storage challenges in mind. This design resulted in a higher East pond to which the 0.2–0.8% surface water gradient (BGC, 2009) was applied resulting with an EPL at roughly 270 masl. At 270 masl, the closure outlet to the Athabasca River could not meet the minimum design criteria. In other words, the lake was too high to allow for the construction of an acceptable closure outlet.

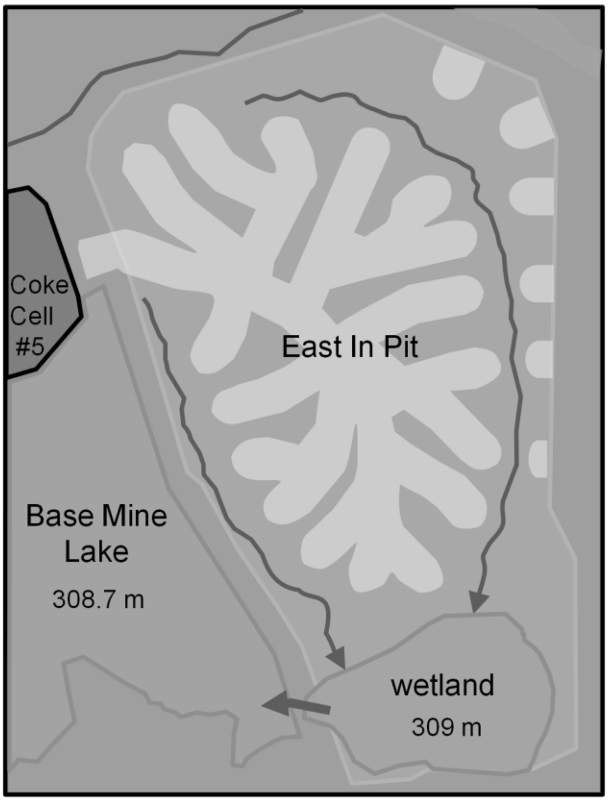

Figure 3 Two-dimensional conceptual closure drainage plan for Syncrude's Mildred Lake East Pit

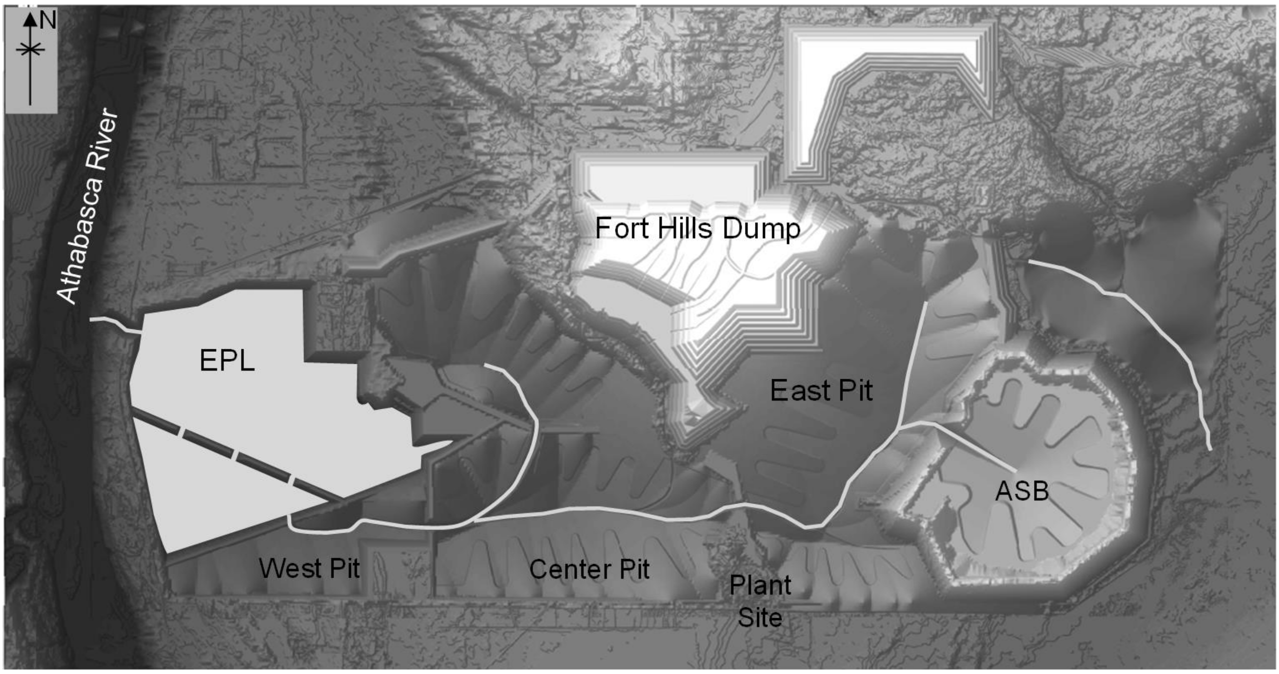

Figure 4 Three-dimensional final closure topography for Syncrude's Aurora North lease

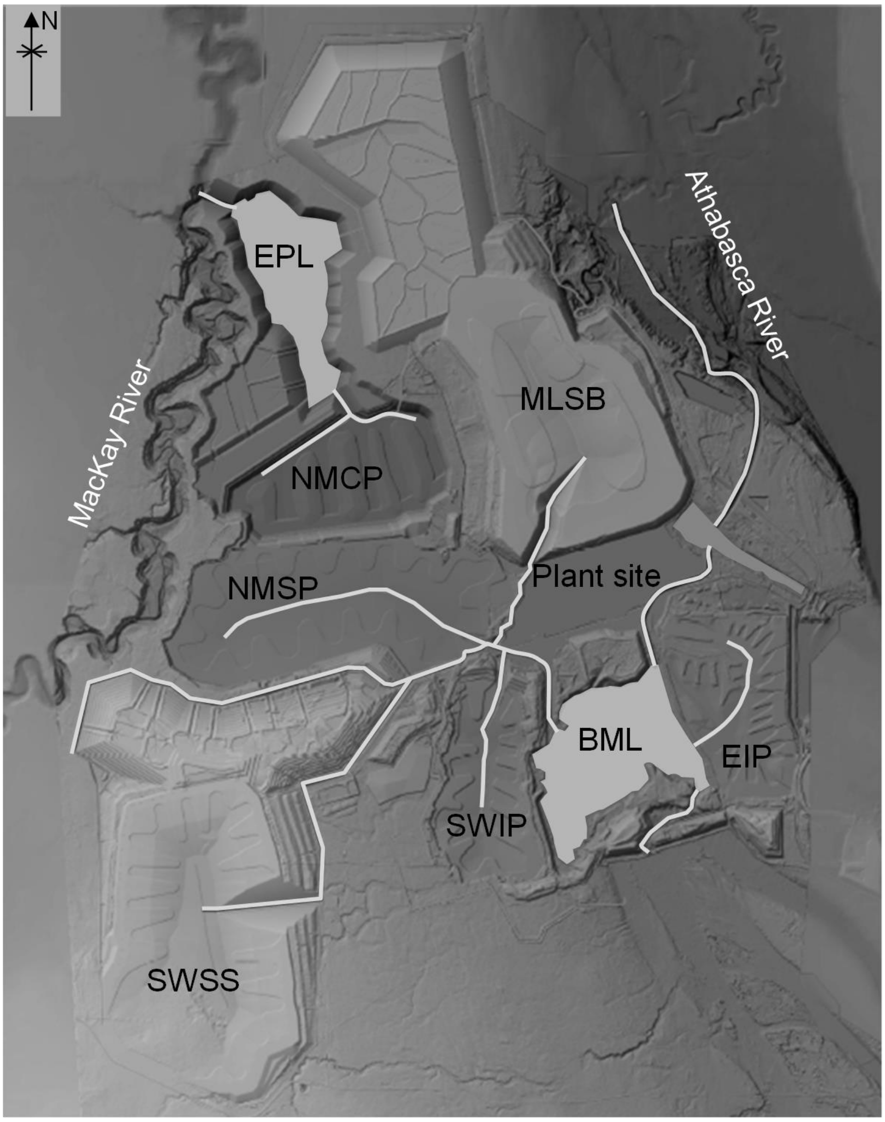

Figure 5 Three-dimensional final closure topography for Syncrude's Mildred Lake lease

Closure planning during 2010 provided maximum tailings infilling volumes for each mined out pit by designing continuous 3-D closure topography for Aurora North including connection to the Athabasca River and breach of the Aurora Settling Basin, as depicted in Figures 4 and 6. The result of this planning was the reduction of total tailings space available in East pit by approximately 48 million cubic metres. This created a fluid containment shortfall in the 2018 to 2022 timeframe as the East pit was at maximum fluid capacity but mining would not have readied the next containment area. To solve this issue, several iterations of the mining and tailings plans were completed in order to design more short term containment in the East Pit, thereby delaying the need for the next tailings pond. Also, borrow pits (from future mining areas) were identified as a means to supply more quality overburden for construction of Dyke 3, which separates Center Pit into a north and south pit, in a timely manner to provide tailings containment capacity as mining is completed.

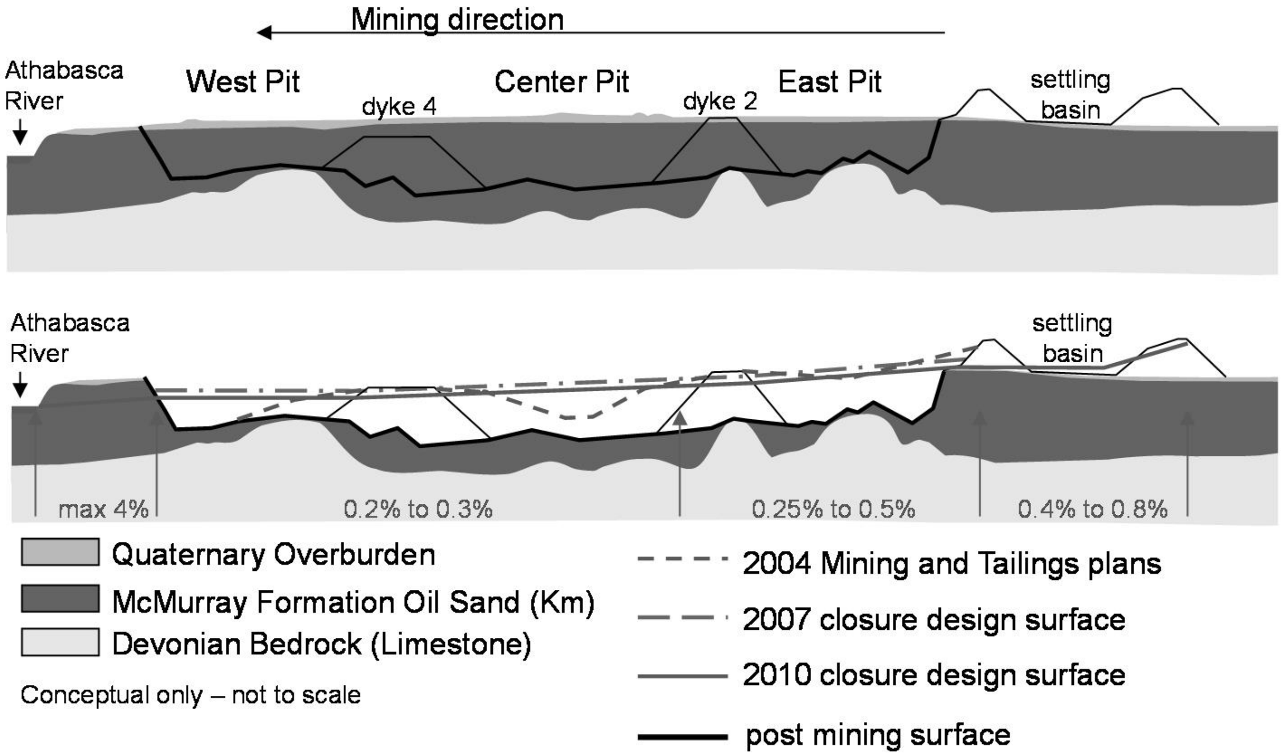

Figure 6 Aurora North closure topography cross section

4.2 Mildred Lake

The final closure design for the Southwest Sand Storage (SWSS) was changed as a result of the work completed to support the 2011 Life of Mine Closure Plan submission. The beaches of the SWSS facility are required to create a Dedicated Disposal Area (DDA), as required by the Alberta Energy and Utility Board's Directive 074 (ERCB, 2009), for centrifuge cake, a tailings technology designed to reduce the final volume of fluid fine tailings at the Mildred Lake site. As a result of the detailed DDA planning, the economics of the closure design for SWSS changed significantly in this plan. It is expected that future iterations of the closure plan and continued research and development will trend the economics in a less negative direction.

Surface water control features were required to meet closure reclamation criteria. The SWSS now has a 3-D closure design that identifies hummocks that support an overall drainage and breach design. Syncrude has mechanically built hummocks on the Sandhill Fen, located on the northwest corner of EIP, and is hydraulically building hummocks on the remainder of EIP, with the latter being the preferred construction method for future projects. The centrifuge cake will be placed on the final beaches of the SWSS facility, which will limit the ability to construct hummocks hydraulically, and the centrifuge cake will have to be removed in order to build the necessary closure landforms. Volumetrically, the centrifuge cake and the sand from the SWSS breach create the necessary topography in the centre of the SWSS facility to create drainage north and south to the breach location.

At the end of mining the North Mine South pit (NMSP), North Mine Center Pit (NMCP) and the plant site areas have not reached their designed final closure topography as defined by the overall surface drainage path. In order to create a 3-D topography that is volumetrically true the NMSP relies on the centrifugation of all the fluid fine tailings that do not physically fit into one of the two EPLs. For this plan, the NMCP relies on coke deposition until 2070 to reach its final closure topography. The plant site relies on material from the Mildred Lake Settling Basin (MLSB) breach and the final canal connecting Base Mine Lake to Beaver Creek to reach its final closure topography of 308.7 masl. Final closure topography for the Mildred Lease with major drainage features identified is shown in Figure 5.

5 Conclusions

Three-dimensional closure topography was developed by integrating the individual landform designs (geotechnical and planning designs) into a single digital elevation model that is integrated within the leases and into adjacent land. This use of a 3-D closure topography as a planning tool was instrumental in identifying key gaps and ensuring a sound physical planning basis that fed the Phase 2 – Reclamation planning elements for the Aurora North and Mildred Lake closure plans. Reclamation plans are now linked to realistic progressions of the mining and tailings plans. The confidence in and the credibility of these plans are greatly improved. Additionally, the 3-D closure designs are available to planning groups to ensure that execution plans will meet closure goals more effectively than the conceptual 2-D designs.

The development of the continuous 3-D models at both Aurora North and Mildred Lake leases has put Syncrude into the position where closure planning is integrated at all levels of the organisation and individual planning groups are working to the same end goal. The closure planning exercises completed through 2010 and 2011 provide Syncrude with a fully developed, volumetrically true "Base Case" that will continue to be optimised through each new iteration. The mine plans reflect prioritisation to uncover dyke footprints and pond areas in a timely fashion to meet tailings goals. Tailings plans are developed with a final closure design in mind that limits total solid volumes available in each area. Although the timing of very specific elements will change, the sequence of events will remain the same, and the end goal, i.e. the closure landscape will remain in view.

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