# Reclamation Strategies that Address Mine Closure Drainage

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# RECLAMATION STRATEGIES THAT ADDRESS MINE CLOSURE DRAINAGE

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## 1. Introduction

Surface water and topography are linked features that fundamentally affect the performance of constructed landforms. Topography affects areal and temporal distributions of surface water because of its effect on soil drainage, rate of runoff and infiltration. Surface water interacts with topography by hydraulic soil erosion that affects the evolution of landform topography.

Unlike natural landforms that have been subject to 1,000's of years of change by natural erosion and sedimentation, constructed landforms are vulnerable to relatively high rates of erosion if the topography is not contoured to suit shapes that represent a dynamic equilibrium in natural systems.

Soil erosion is a most frequent cause of constructed landform deterioration, sediment accumulation and reduced aquatic habitat. Despite its seemingly small rate, erosion represents a high environmental risk after mine closure as a result of its progressive nature. Changes in landform configuration caused by soil erosion include slope failures due to toe erosion of vulnerable slopes, gullies that penetrate through protective covers, drainage channels that adjust to suit a new characteristic regime, and hillslope degradation. Perhaps the most catastrophic impact of erosion is the breaching of dam embankments resulting in runout of tailings materials or effluent. Erosion is a progressive phenomenon whose cumulative impact is governed by recurrent extreme hydrologic events. Studies have shown that erosion is episodic. Normal year to year landscape evolution may not be indicative of long-term trends.

Based on a tour of fifty-seven abandoned and partially reclaimed operating mines, McKenna and Dawson (1977) created an inventory of mine closure practices, physical performance of the reclaimed mine land and environmental impacts of reclaimed and abandoned mines. The inventory shows that the greatest physical risk to the landscapes is associated with surface water erosion (gullying) and re-established surface water conveyance systems.

Constructed landforms can be designed to suit a wide variety of land uses, a range of biological productivities, various ecosystems and various performance objectives. Topography and surface water conditions are important controls that can be used in conjunction with soil cover material to control vegetation type, vegetation diversity, wetland/lake/stream habitat and associated ecology.

Wet landscape is associated with large flat land that is poorly drained. Dry landscape is associated with steeper slopes and a degree of relief that improves drainage and minimizes water logging.

Erosion, landform evolution, landform performance and ecological productivity can be controlled by planning topographic configurations and surface water conditions. But such plans must be developed well in advance of landform development. The desired endpoints may be achieved economically if the closure plan is carefully developed during the initial stages of mine planning when it may be possible to provide for the essential topographic features of the closure landscape. In contrast, developing the desired landform grading plan after initial construction may result in higher costs and possible reduced performance.

## 2. Hydrology of Reclaimed Mine Land

Almost any type of hydrologic regime can theoretically be achieved on mine disturbed landforms. However, cost constraints will limit opportunities to a few that are affordable.

Typically, mine disturbed land is composed of steeper terrain, reduced topographic complexity and thin cover layers of organic soil relative to predevelopment conditions. Without mitigation such features result in higher flood peaks, reduced low flows, and reduced water retention to support vegetation. This might result in increased erosion, reduced vegetation productivity and inferior aquatic habitat. In contrast, natural conditions in the Alberta oil sands region are characterized by large areas of muskeg terrain and relatively thick layers of peat over much of the land area. These natural conditions are associated with very low rates of erosion and relatively uniform streamflow conditions that may support a superior aquatic habitat.

The remedial measure for disturbed mines landforms is to provide lakes and wetlands in the mine closure landscape. Such features will attenuate surface runoff to reduce peak flows and increase low flows so that aquatic habitat of mine drainage systems and receiving waters can be optimized. Whereas these features may restore the natural hydrologic regime of downstream aquatic systems, they do not restore the hydrologic regime of upland topography to natural conditions. Upland hydrology will invariably be permanently altered.

Hydrologic analysis of constructed landforms and downstream effects is required during design so that topographic controls can be used to mitigate any negative impacts. Hydrologic analysis is also used during environmental assessments to predict hydrologic impacts of development.

Various analytical tools have been developed to assess the hydrology of reclaimed mine land in the oil sands region of Northern Alberta. Simple even-based rainfall-runoff models such as the SCS curve number approach have been used in the past to characterize peak flows. More recently, the HSPF model has been developed to simulate the full range of flows so that a representative flow series can be developed for any type of landscape. The HSPF model has been calibrated based on several long-term gauged natural basins and it has been verified based on other smaller basins that have been gauged for only a few years. Simulated flows for more complex reclaimed areas were developed by adjusting physically based parameters of the calibrated model to suit the relief, drainage network, soil conditions and vegetation of various types of reclaimed areas on constructed landforms.

Two types of HSPF model calibrations are currently in use. Both are designed to replicate the statistics of measured flow on gauged basins. Specific hydrographs cannot be replicated in the absence of an instrumented watershed. One attempts to reproduce the statistics of measured flow based on a concurrent rainfall and stream flow record, assuming precipitation at For McMurray is representative of precipitation at the gauged basins located some 80 km north. The other is based on non-concurrent precipitation and runoff data to maximize the period of record for calibration. The latter is based on the assumption that precipitation at Fort McMurray may not be representative of precipitation at the gauged basins during the period of flow record.

## 3. Mine Water Management Principles

### 3.1 Objectives

A comprehensive water management plan is needed to develop sustainable landforms after mine closure, to maximize beneficial impacts and to minimize negative impacts. The following objectives should be incorporated into the mine water management plan:

- restore surface flow regime of receiving waters;

- minimize negative aquatic impacts on the receiving waters;
- provide for suitable moisture conditions at dry land and wet land terrain types;
- minimize risk of flooding and waterlogging at dry land terrain;
- avoid excessive erosion and sedimentation that would lead to failure of the landform;
- avoid catastrophic failure of liquid impoundments;
- minimize costs of construction, operation and maintenance;
- target maintenance free condition after prolonged periods of monitoring
- provide for progressive mine site reclamation and closure;
- control salinity of closure landscape;
- provide for biologically productivity and ecological sustainability, and;
- provide bio-remediation and water treatment capabilities (e.g., wetlands, floodplains, and end-pit lakes).

Landforms and closure drainage systems will need to be designed to comply with these objectives. The landform configuration and drainage design should enable economical mine development with minimum risk to mine operations and closure, and minimum negative impact to the environment. Closure landforms and drainage systems should be sustainable, targeting no maintenance after a period of monitoring and management.

### 3.2 Criteria

The above water management objectives can be achieved if the mine plan and reclamation activities comply with the following criteria that have been proven at other existing oil sands mines.

- Structures such as dams and reservoirs that are vulnerable to catastrophic fluid spillage should be excluded from the closure landscape.
- Drainage systems should be designed to accommodate gradual change over geological time frame and sediment yield from reclaimed surfaces should be comparable to those from natural systems. Drainage systems should be designed to achieve comparable robustness, self-healing capability and longevity as natural systems.

- Wetlands and lakes for flood attenuation and bio-remediation (covering at least 5% of mine disturbed area) should be provided as part of closure drainage systems to mitigate loss of muskeg terrain that attenuates flows in pre-disturbed areas.
- Runoff from closure drainage systems should meet water quality guidelines for mine closure (OSWRGTWG, 1996).
- Seepage of process affected water from tailings ponds and in-pit tailings storage areas should not adversely affect the aquatic health of receiving waters.

## 4. Landform Configuration

The complexities and dynamics of landscapes include various physical processes that may not be fully understood. Nevertheless, the closure landscape must be composed of sustainable landforms that may evolve and degrade slowly while at the same time meeting the goals of physical stability, containment of wastes, and various land use objectives. With an imperfect understanding of the physical processes and an inability to predict future performance precisely, the landform designer needs to adopt an approach which accommodates the inherent uncertainties of an evolving landscape. Such an approach might include the following measures:

- Patterning landform configurations after natural analogues;
- Designing the landscape with multiple lines of defense against failure modes;
- Designing robustness into the landscape in which the system becomes more stable with time;
- Constructing "fire-breaks" into the landscape that limit the transmission of certain failure modes. Examples include use of large lakes as sediment traps and flow attenuators, offsetting receiving streams from major structures to lessen the risk of siltation, and using chemically reactive barriers to arrest the flow of contaminants;
- Designing conservatively using proven technology where available;
- Limiting the use of man-made materials such as pipes, gabions and concrete, and;
- Allowing release of contaminants slowly at acceptable levels over time rather than attempting to contain them forever.

The historical approach to configuring landscape for reclamation was to develop uniform slopes conforming to neat lines and grades complete with benches or terraces that were somehow expected to minimize erosion. However, such design uniformity may not achieve the mine closure objectives of minimum erosion and long term sustainability. Uniform landforms represent immature topography that may be poised to evolve by accelerated erosion. In contrast, the development of sustainable landscape for mine closure, should involve design of landforms that replicate natural landscape to minimize risk of structural failure, reduce the rate and risk of accelerated erosion and develop self-healing erosion control systems.

Examples of natural analogues for reclamation of mine disturbed land follow:

- Mature (non-uniform) topography. Mature topography has been subjected to the rapid erosion of its previous immature state, and has evolved to a state of relative slow change. Mature landform topography can be characterized by relatively short steep slope lengths at the headwaters with slopes becoming gentler as flow concentrates in the downslope direction. Flow paths are located in well defined swales which are deep enough to handle extreme floods, thereby avoiding spillage into another swale or sub-basin. Instead of uniform slopes, mature topography has variable slopes with hills and valleys that serve to improve vegetation diversity, provide protective habitat for wildlife and avoid large surface flow rates on steep slopes. The degree of non-uniformity or amount of relief may be patterned after equivalent natural landforms.
- Reduced slope length at steep slopes. Steep slopes are acceptable as long as the contributing drainage areas are small. The allowable slope length and steepness are a function of the density of vegetation and root mass, soil credibility, and infiltration capacity of the soil (Schumm 1977). Slopes covered by dense grasses that develop a thick root mass are highly resistant to erosion. Allowable slopes at such areas may be steeper and longer than areas with a sparse vegetation cover. Cohesive soils are less erodible than sandy soils and therefore can support steeper slopes with larger catchment areas.
- Avoid ponding on terraces. A common misunderstanding is that terraces prevent erosion. Although terraces intercept surface runoff during low intensity storms, erosion can only be controlled if the accumulation of surface water does not exceed the storage capacity on the terrace or if the resulting spillage is properly controlled by a spillway structure. Whereas terraces can prevent erosion in the short term during

normal hydrologic events, they cause accelerated erosion during extreme events when their storage capacity is exceeded. The erosion damage caused by such uncontrolled spills can be very severe as illustrated by many such failures in tropical agriculture. Terracing represents immature topography and is not well represented in nature as an erosion control mechanism.

- Avoid exceeding the maximum overland flow path length. The maximum allowable overland flow path length (MAOFPL) is a landform characteristic that depends on various factors such as climate, soil type, drainage condition, slope and type of vegetation cover. For natural terrain in a given region of common climate, surface geology and soil condition, the MAOFPL is governed mainly by slope and aspect. It can be estimated by examining natural terrain of similar soil conditions and aspect.

## 5. Drainage Systems

### 5.1 Drainage Design Issues Associated with Mine Planning

Achieving the above water management objectives and criteria requires both an appropriate design of drainage facilities and a compatible mine plan. It is important that water management issues be considered early in the mine planning process to avoid mine development that makes it impossible to achieve the above water management objectives and criteria. The following guidelines must be considered early in the drainage design planning process so that essential features can be incorporated into the drainage design:

- The closure drainage system must be suitably integrated with the drainage systems of adjacent mines. Collaboration with adjacent lease holders is essential and should be documented.
- An end-of-mine lake must be developed at the downstream end of all reclaimed sub-basins that contain tailings or process water.
- The maximum surface area of an end-of-mine lake must be less than 10 to 20% of the contributing drainage area to provide sustainable discharges. The actual maximum lake/wetland area will depend on the consequences of flow interruption caused by droughts. The minimum surface area of an end-of-mine lake should exceed 5% of

the mine disturbed drainage area. This is deemed necessary to mitigate removal of muskeg terrain that provides suitable flood flow attenuation and sustained low flows.

- The water volume of an end-of-mine lake must be large enough to allow for bi-remediation of influent seepage and surface runoff. This may require a residence time of 3 to 20 years depending on the contents of the end-of-mine lake.
- The topography of the final landscape of the reclaimed mine area must slope toward end-of-mine lakes.
- The surface of in-pit tailings located adjacent to receiving waters should be below or at natural ground, to minimize or avoid seepage of process affected water to natural streams.
- The separation between an external tailings pond and receiving waters should be as large as possible.
- The difference in final surface elevation between pits containing tailings infill should allow for an overall slope of 0.1% to 0.5%.
- Bouldery/cobble/gravel overburden material should be placed at proposed locations of drainage channels that may be subject to progressive erosion.
- Large drops from natural ground levels to reclaimed in-pit tailings storage areas should be avoided, especially where surface water would flow into the mine pit area.
- Above-ground liquid impoundments should be avoided in the closure landscape (i.e., no dams).
- Any major stream that crosses filled-in mine pits at closure must be suitably designed (i.e., situated on an internal dyke constructed of compacted clay/till).
- The tailings pond should ideally be located on relatively impervious foundation soils.
- The tailings pond should ideally be contained by topography on one side so that the ultimate surface can be drained easily over undisturbed soils.
- The closure drainage plan should restore natural drainage courses to the original receiving waters.
- Overburden dumps and pits should be developed with irregular foot print shapes so that the final landform avoids long linear features that do not resemble natural systems.
- Side hill diversions should be avoided. If they cannot be avoided, they should be developed alongside large barrier fills that prevent spillage in the long term. The

required size of barrier fill varies depending on the size of the stream and vulnerability to beaver dams and ice blockage.

- Fish-bearing streams should be protected to the maximum extent possible.

## 5.2 Drainage Design Issues Addressed at Mine Closure

The above macro scale guidelines must be incorporated into the mine plan and should be clearly understood by mine planners. There are other drainage design guidelines that need to be incorporated later during final design of the closure drainage system as discussed below.

The characteristics of natural streams provide excellent guidance for the design of drainage systems that incorporate passive erosion protection. However, a self-healing character of natural systems must be built into man-made channels by designers who appreciate the inherent stability of natural systems and understand the processes. The resulting drainage systems, based on passive erosion control offer superior performance in the long term. Development costs are not necessarily greater than the cost of conventional structural systems. Through appropriate planning, the cost of sustainable channels that incorporate passive erosion control measures may be less that those of conventional systems which are built with rigid structural erosion protection. Examples of such passive erosion protection measures based on the geomorphic approach are given below:

- Bouldery ground beneath drainage channels. Placement of waste rock or overburden material with high rock content beneath drainage channels, introduces a self-healing capability. If the initial armour of a channel is removed by an extreme flood, channel degradation will expose other rocks and create a new armour layer. Like natural river systems, channels need not be designed to be immobile during for events such as the Probable Maximum Flood (PMF) or even the 100 year flood. The armour layer of natural streams often begin to mobilize during events as low as the 2 year recurrence interval, and are subject to relatively small rates of erosion during more extreme events.
- Suitable drainage density. The maximum allowable slope length of overland flow can be described in terms of drainage density which is the total length of active drainage channels per unit area. Drainage density can be qualitatively related to

dependent parameters such as slope, climate, soil type and vegetation (Schumm 1977).

- Use of regime channels. Instead of providing channel armouring, the landform designer should design regime channels that replicate the dynamic character of natural channels. Some examples of natural channel features include meanders and channel dimensions that conform to regime relationships, floodplains, and sources of channel armour. Channel geometry and meander pattern may be selected based on extensive available data and research by fluvial geomorphologists. There is a large body of literature available for the designer to select appropriate channel parameters that suit the required overall valley gradient and bed/bank materials. The parameters include channel depth, slope, width, sinuosity, meander wave length, and width to depth ratio. The resulting regime channels that are patterned after natural channel characteristics, will exhibit equilibrium conditions, avoid rapid progressive channel degradation or aggradation, and handle extreme events. Riprap erosion control may not be necessary if the channels are designed to be in dynamic equilibrium with the capability to accommodate erosion. Flow capacity can be achieved by building drainage channels in well-defined swales or small valleys, just like natural drainage systems.
- Floodplains to attenuate flows. To reduce flow velocities, the designer may follow the example of natural systems where streams are flanked by floodplains that attenuate flood flows and reduce channel velocities.

This geomorphic approach accepts that drainage channels will change over time and that no attempt should be made to resist slow change over geomorphic time frames. Instead, every attempt should be made to anticipate change so that systems can be designed to accommodate change. Anticipation of changes enables the drainage designer to build robust systems with redundancy.

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