Mine Planning Guidelines for Developing Sustainable Closure Drainage Systems

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By

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Abstract and Biography

Failure of drainage works is one of the principal threats to the sustainability of mine closure facilities but the risk can largely be remedied by appropriate design of mine closure drainage facilities. The feasibility of sustainable mine closure facilities that avoid failure of drainage systems needs to be established during the early stages of mine planning, before mine disturbances make sustainable closure uneconomical. Experience in mine development shows there is often enough latitude in mine plan development to incorporate measures with neutral economic consequence and positive environmental benefit. Project managers need to resist the temptation to develop mine plans and closure drainage plans independently. Integrated mine planning with effective inputs by environmental specialists and drainage designers may affect the overall mine configuration, footprint and schedule. Key issues pertain to the end pit location, waste dump configurations, pit infill elevations, fluid impoundments, diversion channel routing and preservation of flows to receiving waters. Guidelines with illustrations of suitable practices are presented to assist mine planners.

INTRODUCTION

Mine closure planning is best handled during the early stages of mine planning when there is opportunity to accommodate requirements for future mine closure (Sawatsky and Tuttle 1996; Sawatsky, et. al 1997; Sawatsky and Beckstead, 1995). Development of sustainable drainage systems is a key factor that must be addressed in the closure plan that is developed during initial mine planning. Deficient drainage characterized by above ground fluid containments, lack of surface drainage, piping and leaching of contaminants resulted in major failures at Mt. Washington Mine in B.C., Matachewan in Ontario, Los Frailles in Spain and Omai in Guyana. Water flux, either above ground or below ground is the causal factor in failures by erosion, piping or leaching. These factors are more difficult to remedy after mining is completed and after mine closure landforms are established. But, they are often possible to remedy by developing appropriate land forms and closure drainage systems that are achieved by mine planning in advance of mine development.

The goal of preparing a mine closure drainage plan before mine development is to provide low cost drainage works that are sustainable in the long term, require little or no maintenance after a period of monitoring and management, restore ecological productivity and minimize environmental impacts. Performance indicators of effective closure drainage would include gradual evolution of drainage works at geomorphic time scales, minimum flooding and water logging, effective conveyance of extreme floods, no salinization of surface soils, biologically productive landscape, suitable water quality and restoration of flows to natural receiving waters. Drainage works should ideally replicate the regime (geomorphic character) of natural streams, and provide dynamic stability, robustness, and self-healing capability.

This paper presents high level guidelines for planning effective mine closure drainage systems that are best incorporated in mine planning prior to mining activities. Therefore, this paper does not address design criteria and parameters that are applied during detailed design at the time of drainage construction. The focus of this paper is on oil sands mines in Northern Alberta, but most of the guidelines are generally applicable to a wide range of mines and locations.

DRAINAGE LAYOUTS

The principle drainage layout issues to be addressed during the early stages of mine planning are restoration of flows to receiving waters and major drainage/diversion routes. To the maximum extent possible, pre-development surface flows to receiving waters should be restored. Some deviations are tolerated since it is impossible to replicate pre-mining conditions precisely. Rules that have been accepted in previous mine approvals in the oil sands region are listed below:

- 10 year flood flows of natural receiving waters should not deviate from pre-development flows by more than 30%, and;
- 2 year flood flows and mean annual flows of natural receiving waters should not deviate from pre-development flows by more than +100% and –30%.

Figure 1 illustrates drainage boundaries that are altered by mining activities. The above criteria can be achieved by constraining such alterations and by attenuating flood flows at man-made lakes that are located at the downslope end of the mine disturbed areas.

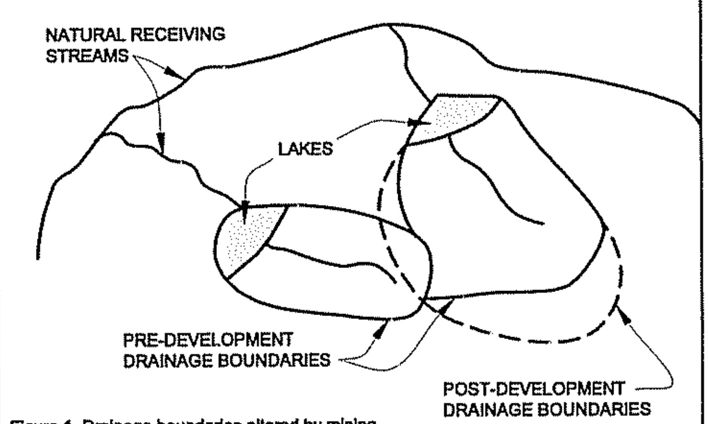

Figure 1 Drainage boundaries altered by mining

Routes of major drainage courses must be planned appropriately so that they avoid vulnerable topographic conditions. Side hill diversions must be avoided since channel aggredation (raising of channel invert by sediment deposits), debris blockage, ice blockage and beaver dams can cause spillage and permanent relocation of the drainage course. Sometimes, it is impossible to avoid a side hill diversion. Then it is necessary to construct large barrier fills to create permanent impediments to channel relocation, as illustrated in Figure 2.

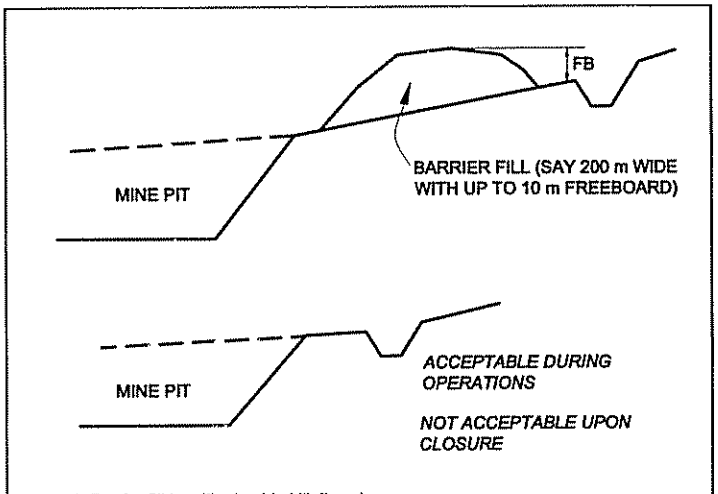

Figure 2 Barrier fill to mitigate side hill diversions

There are many other layout requirements pertaining to drainage density, maximum overland flow path length, pattern and channel regime that are important to consider during detailed design, but they are beyond the scope of this paper.

END-OF-MINE LAKES

End-of-mine lakes are waterbodies in the mine closure landscape. They include end-pit lakes and other constructed lakes that are both needed for flood flow attenuation and bioremediation of process affected flows. End-pit lakes are the result of mining activities. The endpit is the final pit of a mine operation. It cannot be infilled with overburden or tailings material because it occurs at the end of mining when mine operations cease. Other types of end-of-mine lakes include pit areas that are not fully backfilled during mining, to establish a lake in the mine closure landscape. At oil sands mines, lakes are needed at the downslope end of mine site drainage to attenuate flood flow and provide enough residence time so that process affected water containing naphthenic acids is subject to natural degradation and bio-remediation sufficient to comply with toxicity requirements.

To provide effective residence time for all process-affected water in the mine closure landscape, end-of-mine lakes must be located at the downstream end of the mine disturbed topography as illustrated in Figure 3. Ideally, a single end-pit lake is located at the downstream end of the mine disturbed drainage basin. However, actual site conditions may involve multiple drainage basins and several end-pits that cannot be backfilled. Accordingly, any unfilled pit should be situated at the downstream end of the mine disturbed area. Additional end-of-mine lakes must be developed at the downstream end-of-mine disturbed drainage basins that do not have end-pits.

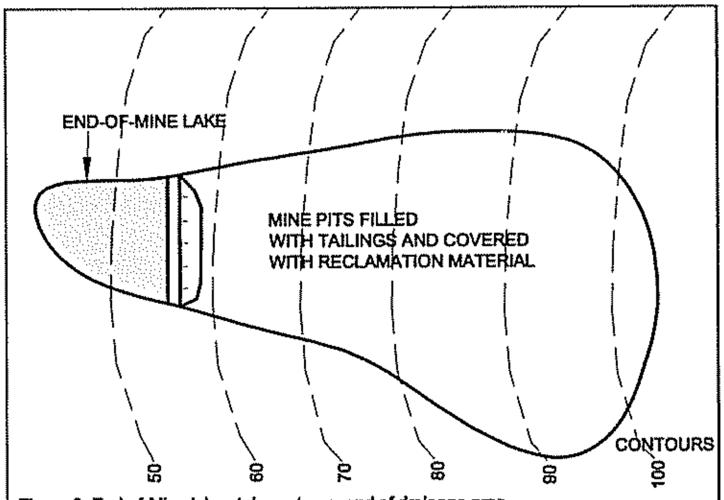

Figure 3 End-of-Mine lake at downstream end of drainage area

The allowable surface area of an end-of-mine lake depends on local hydrologic and climate conditions. At the oil sands region in Alberta, the maximum lake area should not exceed 20% of the total drainage area so that outflows are maintained during dry years. The minimum lake area at oil sands mines should exceed 5% of the mine disturbed area to provide a suitable degree of flood flow attenuation that was lost as a result of land disturbance for mining. There is a minimum required end-of-mine lake volume for the oil sands mines. The required volume varies depending on the presence of fine tailings or other mine waste materials in the lake and on the proportion of process-affected inflows from seepage and surface water runoff relative to meteorologic inflow. For preliminary planning of end-pit lakes at oil sands mines that contain process water and residual fine-tailings, the minimum volume (m^3) should exceed the mine disturbed area (m^2) multiplied by 2 (m) offering a residence time of about 20 years. The minimum volume (m^3) of other end-of-mine lakes that do not contain process water and residual fine tailings at the end of mining, may be smaller, equal to the disturbed area (m^2) multiplied by 0.33 (m) to achieve a residence time of about 3 years. These criteria are illustrated in Figures 4 and 5. However, detailed EIA level water quality modelling must be completed to confirm these assumptions.

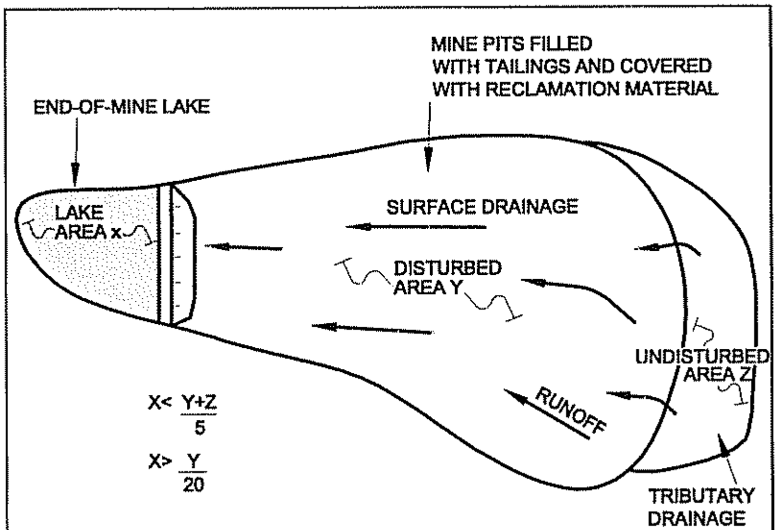

Figure 4 Area of end-of-mine lakes at Oil Sands Region

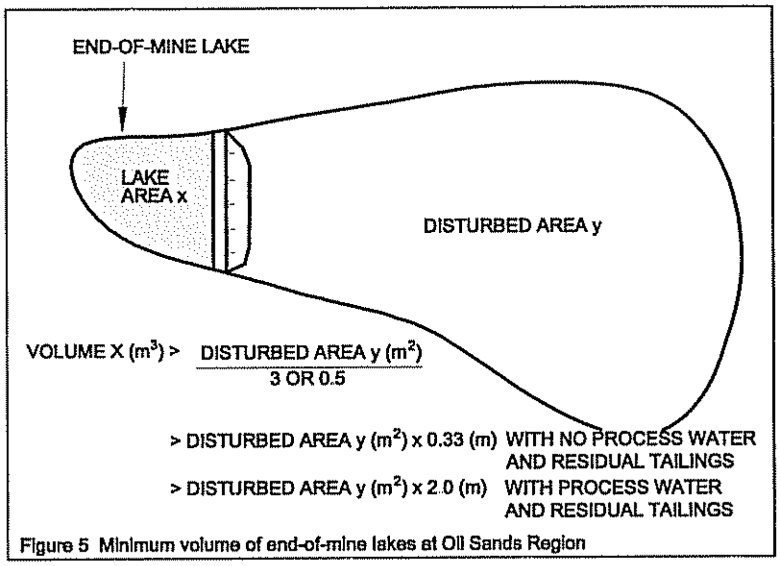

Figure 5 Minimum volume of end-of-mine lakes at Oil Sands Region

LIQUID IMPOUNDMENTS

Liquid impoundments are defined herein to include water reservoirs, tailings ponds containing process water and tailings areas containing liquifiable solids. Such impoundments should ideally be located below original ground level to permanently contain the liquid or liquifiable solids without risk of spillage causing catastrophic impacts. Some impoundments like tailings ponds for initial operations are necessarily located out-of-pit as illustrated in Figure 6. In Alberta, such impoundments must be dewatered upon mine closure to avoid above ground liquid impoundments and catastrophic liquification failures, according to current regulatory requirements.

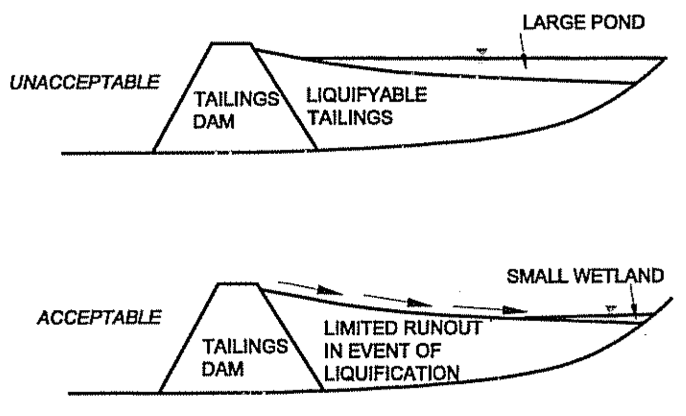

Figure 6 Avoiding above ground liquid impoundment in oil sands region of Alberta

LANDFORM CONFIGURATION OF MINE DISTURBED AREAS

Landforms that are created by mining activities must conform to various criteria that provide for sustainable drainage. One important criterion is gradient. Mine disturbed material is normally much more erodible than pre-mining conditions and therefore the overall gradient may need to be smaller than undisturbed soils. For pits that are infilled with CT (composite tailings or consolidated tailings) at the oil sands region of Alberta, a typical maximum gradient of 0.5% is applied to pit infill areas as illustrated in Figure 7. Higher gradients are achievable where the major drainage course passes through undisturbed soils.

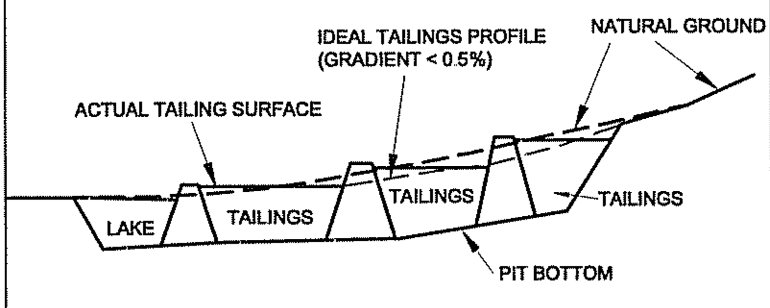

Figure 7 Gradient of infilled pits

Ideally, the level of pit infill tailings material should be at original ground level as illustrated in Figure 8. This is preferred to avoid surface drainage discontinuities. In the oil sands region, in-pit fine tailings should not exceed original ground levels where seepage outflows could cause excessive process affected water to discharge to natural receiving waters. If such a condition leads to excessive impacts to receiving waters, a seepage cutoff may be required to control impacts.

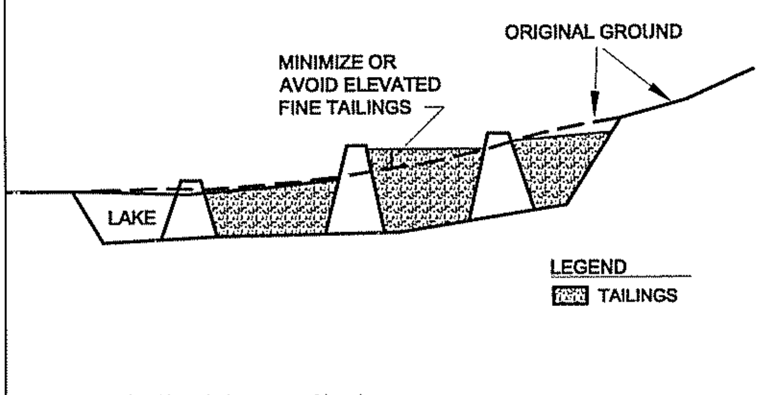

Figure 8 In-pit tailings below ground level

Large drops between natural ground levels and in-pit tailings storage areas as shown in Figure 9, are not acceptable at the surface inflow areas because such drops could cause significant gullying and surface erosion.

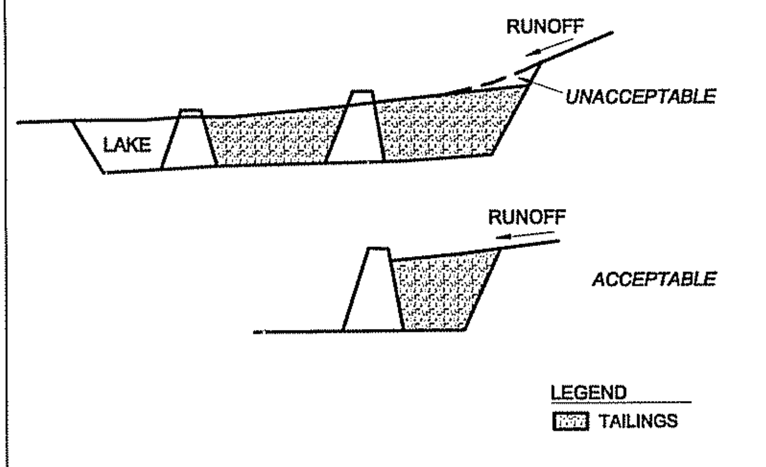

Figure 9 Avoiding large drops at surface inflows

Overburden dumps, end-of-mine lakes, and pit boundaries should ideally be built on an irregular footprint as illustrated in Figure 10, to avoid shapes with long linear features. Irregular planforms are associated with significant benefits such as wildlife escape habitat, vegetation diversity and surface drainage sustainability, relative to straight edges that are often configured to suit lease boundaries and survey efficiency.

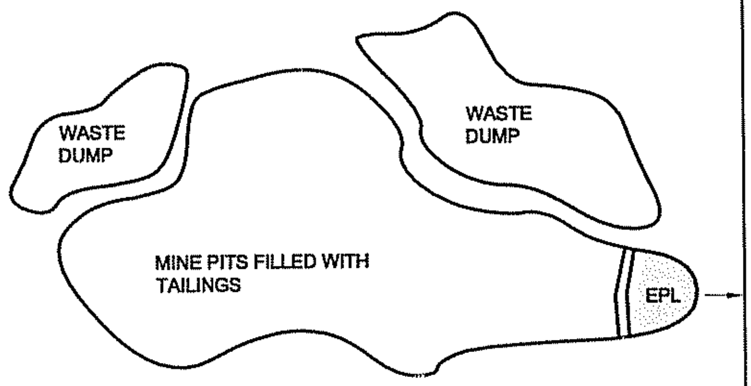

Figure 10 Irregular footprint of mine pits, waste dumps and end-pit lakes

External (above ground) tailings ponds should be designed to control seepage thereby preventing excessive process-affected seepage flows to receiving waters. This may be accomplished by founding the ponds on relatively impervious soils as illustrated in Figure 11, by locating the pond far-removed from receiving waters as illustrated in Figure 12 and by seepage control systems (cutoff wells, interceptor wells, etc.). Tailings ponds should ideally be situated alongside a hillside as illustrated in Figure 13 so that discharges from the reclaimed area at mine closure can be safely handled by an outlet channel on undisturbed ground.

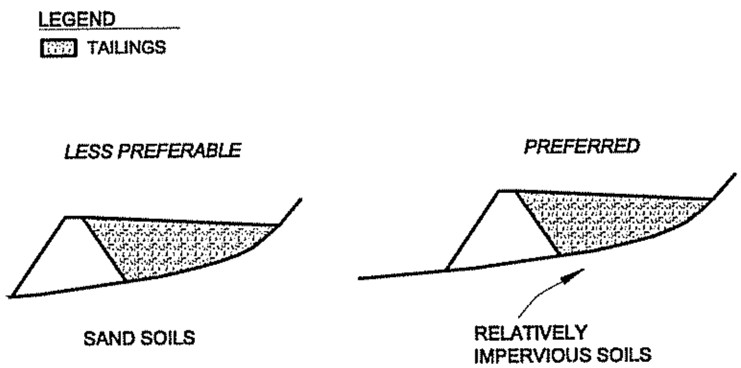

Figure 11 Tailings pond configuration

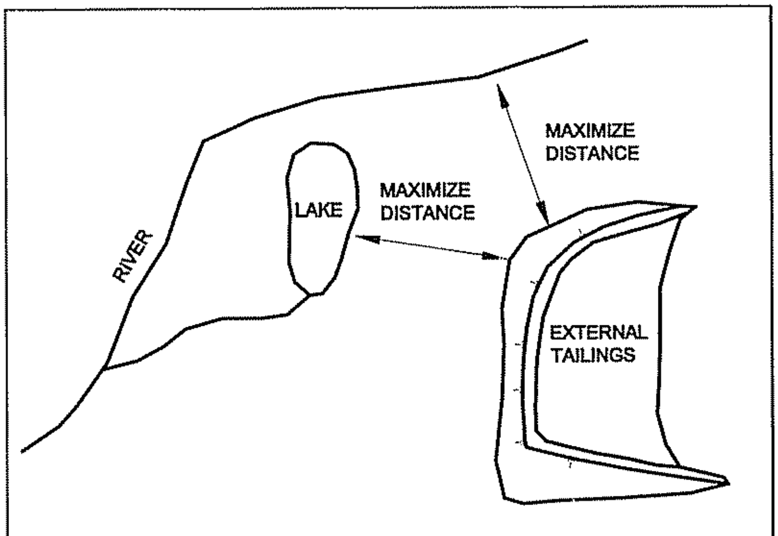

Figure 12 Tailings pond location

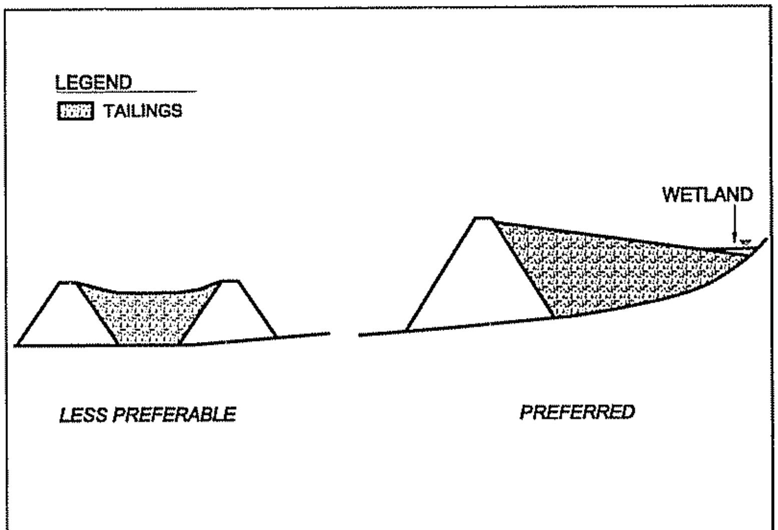

Figure 13 Tailings pond contained by topography on one side

MAJOR DRAINAGE COURSE ON DISTURBED GROUND

Major drainage courses should normally be located on undisturbed ground at gradients that do not lead to excessive erosion. That is not always possible. Often a major drainage course must cross a pit infill area. One option is to provide an internal dyke at the crossing location so that the channel can be situated on compacted soil to suit specifications designed to minimize erosion. This option is illustrated in Figure 14. Another option is to fill the area with select overburden materials that contain cobbles and boulders as illustrated in Figure 15. This will provide a source of granular armour in the event of erosion.

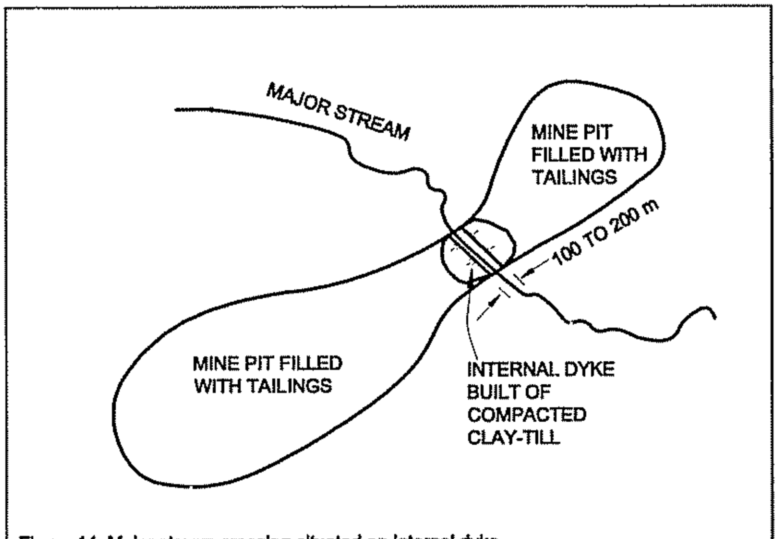

Figure 14 Major stream crossing situated on internal dyke

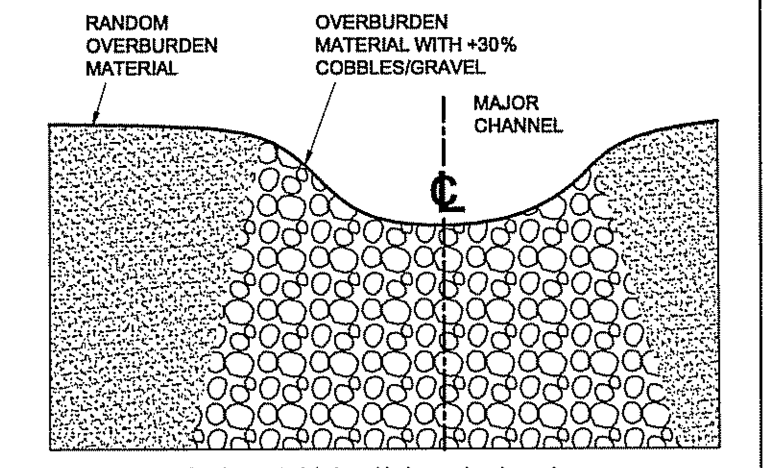

Figure 15 Select overburden material placed below major channels

REFERENCES

Sawatsky L. and Tuttle S. (1996). Occurrence and Growth of Gullies on Mine Disturbed Land. Presented at the 21 Annual Meeting Canadian Land Reclamation Association, Calgary, Alberta, September 18 - 20, 1996

Sawatsky L., McKenna G., Keys, M., Long, D., (1997). Solutions for Minimizing long-term liability of Reclaimed Mine Sites. Canadian Institute of Mining, Vancouver, B.C. April 27 - May 1, 1997.

Sawatsky L., and Beckstead G. (1996). Geomorphic Approach for Design of Sustainable Drainage Systems for Mineland Reclamation, Annual conference of the Canadian Society for Civil Engineering, June 1 - 3, 1995, Ottawa, Ontario