Towards Minimising the Long-term Liability of Reclaimed Mine Sites

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Towards Minimising the Long-term Liability of Reclaimed Mine Sites

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Abstract

Reducing long-term liability is becoming increasingly important as mine owners and financiers become aware of their obligations after mine closure and reclamation. Certification of reclaimed mine land does not necessarily relieve owners of their responsibility if failure or severe environmental impacts after closure are attributed to deficient reclamation planning, design and implementation. Therefore, it is necessary for owners to factor long-term liability into mine plans in an attempt to minimise their exposure. At many mines, end-of-mine landforms are inherently stable and subject to minimal long-term change and environmental degradation. Other mine land is subject to gradual or rapid evolution, which can eventually result in negative environmental impact and reduced land productivity. Neglecting these long-term impacts may result in significant unexpected financial obligations. If the owner attempts to control landscape evolution by conventional structural or operational measures, a substantial bond may be required to cover perpetual maintenance. An alternative is to build robust, self-healing reclamation landforms that replicate the dynamic evolution and character of natural systems, thereby minimising long-term liability.

INTRODUCTION

Long-term liability has become an important issue for mine operators as their legal obligations are being enforced through the regulatory process as well as by third-party interventions. Shareholders and bankers are

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beginning to insist on full disclosure of mine closure obligations and post-closure environmental impacts. This is a relatively recent phenomenon. It reflects a sharp contrast with mine ventures of previous decades when reduced land productivity and risk to the environment seemed to be treated as inevitable consequences of development. In Canada, tougher provincial and federal regulations have imposed new standards of reclamation practice and restoration of land productivity. Mine owners and directors have been made accountable for negligent planning and operating procedures to the extent that company directors can be held criminally responsible for decisions by their staff that lead to environmental degradation. Mine owners cannot escape the obligations of developing a sustainable mine closure system. Accordingly, it has become essential to include the long-term liabilities associated with mine closure in any inventory of current asset value.

For some sites, particularly existing mines built without sustainable reclamation strategies, it may not be possible to reduce long-term liabilities to zero, and some long-term maintenance of these sites may be unavoidable. However, by careful closure planning and by dividing the landscape into units or blocks, almost all of the landscape can be returned to an essentially 'maintenance free' condition by designing a landscape that will evolve at rates similar to those of surrounding natural areas. Despite such action, it is of course likely that these will remain some units that will require minor maintenance on an as-required basis, for which a financial bond may have to be posted by the mine.

This paper describes some important causes of long-term liability and compares several alternative approaches, which may be taken during mine operation or upon mine closure. These recommended approaches aim to minimise liability and reduce overall costs.

TYPES OF LONG-TERM LIABILITIES

Potential long-term liabilities associated with mine development are illustrated by the conditions on previously abandoned and reclaimed mines. There are many examples of mines abandoned earlier in the 1900s, which would result in large liabilities were they decommissioned in the 1990s. The poor environmental conditions on many of these abandoned mines are an impediment to the modern mining industry. Their existence makes it difficult for the industry to gain credibility with regulators and the public. Despite recent successes, stringent mine permit conditions and bonding for premature mine closure, the mining industry continues to be plagued by the legacy of abandoned mines, where liability has been transferred to the public as a result of bankruptcies.

Based on a tour in Canada of fifty-seven abandoned and partially reclaimed operating mines, McKenna and Dawson (1997) created an inventory of mine closure practices, physical performance of the reclaimed mine land and environmental impacts of reclaimed and abandoned mines. The inventory establishes several types of residual liability associated with mine closure. However, the greatest physical risks to the landscapes was associated with surface erosion (gullying) and the poor performance of drainage on the re-established site. The key problems, therefore, pertain to the various aspects of surface water hydrology that are affected by mine closure and reclamation.

Reduced Land Productivity

In Canada, current mine permit conditions commonly require that mine-disturbed land must be restored to previous levels of land productivity, often allowing some changes in land use. Such conditions aim to counter the problems caused by the mine closures of previous generations, which have produced less productive and sometimes effectively sterile landscapes. The intention is that a mine operator's inability to comply with permit conditions governing land productivity will result in a significant long-term liability.

Water Quality Impacts

Major water quality impacts of mine developments include acid rock drainage, leaching of heavy metals from waste-rock piles, and pore-water seepage from the tailings disposal areas. These impacts represent a significant cost for remediation either by engineered structures such as cutoff barriers, impervious covers and containment, or by water treatment. The last might include flushing waste rock upon mine closure to reduce long-term impacts, or continued water treatment, possibly in perpetuity. Such residual liabilities loom large, particularly if they are not addressed until the end of mine life.

Catastrophic Failure of Reclaimed Landforms

The catastrophic failure of reclaimed landforms is normally associated with geotechnical instability of waste dumps, mine cut slopes, deep excavations and dam failure. Unfortunately, the successful performance of mine-disturbed land during the first few years after mine closure may not be indicative of future stability because such failures can be affected by uncommon events such as earthquakes, increased piezometric levels caused by wet periods or extreme hydrologic events, and or by progressive changes in the physical configuration of landforms as a result of erosion and gullying. This type of occurrence affects land-use, land productivity and water quality. It is generally unexpected and costly.

Erosion and Gullying

Although often overlooked, soil erosion is a most frequent cause of landform deterioration, sediment accumulation and reduced aquatic habitat. Erosion is a progressive phenomenon with a cumulative impact that is governed by recurrent extreme hydrologic events. Erosion is episodic. Normal, year-to-year, landscape evolution may not be indicative of long-term trends. The degree of long-term liability associated with erosion varies depending on the rate of erosion, impact of the resultant landscape evolution and sediment yields. The cost of remediation can be very high if the end-of-mine landforms are not designed to accommodate the progressive forces of erosion.

Despite its seemingly small rate, its progressive nature makes the erosion of landforms after mine closure represent a high risk of environmental impact. Adverse changes in landform configuration that result from soil erosion include: slope failures due to toe erosion of vulnerable slopes, gullies that penetrate through protective covers, drainage channels that adjust to a new characteristic regime by incision, channel widening or aggradation, and hillslope degradation. Perhaps the most catastrophic impact of erosion is the breaching of dam embankments that results in the runout of tailings or impounded effluent.

Liability Related to Evolving Regulation

One of the greatest liabilities for a mine is changing retroactive environmental legislation. Working with the regulators, mines need to develop clear and measurable site-specific performance goals and an agreement that meeting these goals will absolve the mine from future changes in regulation.

WHEN TO ADDRESS LONG-TERM LIABILITY

The time to address long-term liability is 'now'. Ideally it is done in the prefeasibility stages. This is when the greatest savings and environmental protection can be achieved. For mines that are currently operating without a closure plan, closure planning should begin as soon as practicable. Experience has proven that closure planning uncovers suboptimal mine plans.

In the past, it may have been possible to ignore the issue of long-term liability. This is no longer an option, given the emergent regulatory climate and accountability to shareholders and lending agencies. Most mine operators now find it necessary to incorporate long-term liability into their internal financial reports as well as their mine environmental assessments for obtaining regulatory approval.

Nevertheless, in some jurisdictions it is still possible to delay preparation of detailed mine closure plans and to postpone reclamation activities. Even where conceptual mine closure plans are required for regulatory approval, mine operators may not prepare adequately for mine closure during operations. There is a strong temptation to delay detailed closure activities until mine closure to defer the cost of such work and to allow for those changes in mine development plans that commonly occur during mining. Radical mine plan changes can make a closure plan obsolete and as a result the effort invested in mine closure may appear to be wasted. Nevertheless, deficient mine closure planning during mine operation and disregard of mine closure costs and liabilities will almost certainly lead to deficient environmental management and increased costs.

A superior response to long-term liability is to be pro-active in minimising liabilities through mine planning that takes into full account mine closure costs and liabilities. The best time to minimise long-term liability is during pre-mine planning and during mine operation, when it is still possible to develop an economical landscape configuration by modest changes to mine plans and waste disposal operations. Measures to minimise long-term liability can be implemented at a much lower cost if planned in advance and if integrated into mine operations. Rehandling of material can be avoided by appropriate planning. The costs of land-forming can be minimised if mine closure work is conducted during periods of reduced equipment utilisation. If detailed closure planning is delayed until mine closure, such opportunities for major reductions in mine reclamation costs will be lost.

An example of the pro-active approach is to reduce the quantity of mine water releases requiring treatment. This can be achieved by controlling the size of mine waste-rock dumps, segregating the mine waste rock into areas subject to acid rock drainage (ARD) and not subject to ARD, landscape contouring to maximise water shedding (thereby minimising infiltration) and placing overburden dumps over ARD waste dump areas. However, the most appropriate time to implement such activity is during mine operation. Once again, the opportunity is lost if mine closure planning is delayed until the end of mining.

In sum, remedying long-term liabilities by physical rehabilitation of mine closure facilities after the end of mine operation can be more expensive than conducting such work during mine operation. Reconfiguring physical facilities after their construction involves double handling of materials and precludes the opportunity for more economical solutions. Post-closure remedial measures may require placement of cover materials from a new borrow area, which may be far more costly than the selective use of mine overburden material during mine operation. The high cost of rehabilitating mine closure facilities after cessation of mine operation is a positive incentive for closure planning during mine operation.

There are several further economic advantages to reclaiming mine-disturbed land progressively during mine operation, which is now required by mine operating permits in many jurisdictions. Firstly, progressive reclamation offers the opportunity to optimise reclamation methods based on experience and to monitor the effectiveness of specific strategies. The outcome may be substantial savings in the costs of reclamation. Secondly, progressive reclamation offers an extended performance record when monitoring may provide a guide to the costs of maintenance and sustainability. This may permit a more accurate costing of maintenance costs and financial bonding. Thirdly, it provides an opportunity to remedy any deficiencies of the reclamation plan in advance of post-project assessment, which will benefit the reputation of the mining enterprise.

STRUCTURAL SOLUTIONS REQUIRING CONTINUED OPERATION OR MAINTENANCE

A conventional method of minimising residual liability is to develop structural systems designed to avoid the negative impacts of mine closure. Structural solutions include impervious covers over waste rock, seepage cutoffs, riprap spillway channels, rock armour covers, dam embankments and various types of landscape configurations designed to control surface water, hydrology, salinity and water quality. Most structural solutions are semi-permanent, requiring occasional repair or replacement after a period of years. Any structural solutions built of concrete, steel or other man-made materials cannot be considered permanent and must be included in the category of continued operations and maintenance solutions. Similarly, many rigid systems such as rock armouring of stream channels may not be permanent, even if the erosion protection is designed for extreme events. The reason is that rigid systems are incompatible with any type of landscape subjected to damage as a result of the natural forces of weathering and erosion. Unexpected occurrences such as frost heave, slope failure, beaver dams, debris jams, ice plucking and root growth can dislodge individual stones and lead to deterioration.

Various types of structural covers over waste-rock dumps subject to ARD and leaching of heavy metals, can be developed to minimise infiltration. These include impervious covers and evapotranspiration (ET) covers that minimise deep percolation by water shedding and evapotranspiration (Fig. 1). These can be built at moderate cost if they are constructed during mining and utilise mine waste materials.

AN APPROACH FOR CONSTRUCTING SELF-SUSTAINING LANDSCAPES

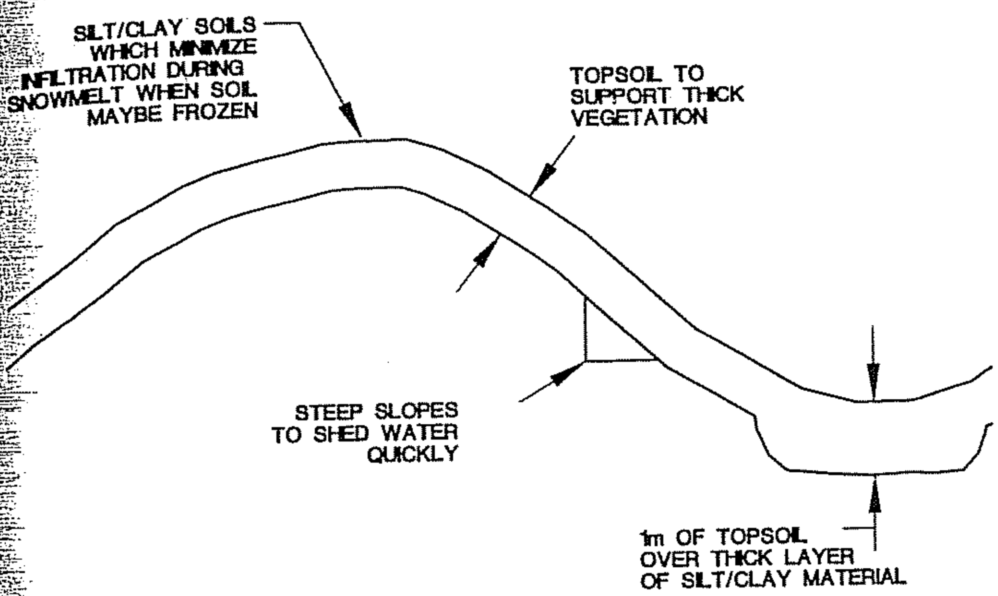


Fig. 1: Hydrologic cover configuration

The complexities and dynamics of landscapes (physical, biological and chemical) are multiple and impossible to understand fully. Nevertheless, the reclamation planner is charged with the responsibility of constructing sustainable landscapes that will continue to evolve and degrade slowly, while at the same time meeting goals such as physical stability, containment of wastes and various land-use objectives. With an imperfect understanding of nature and unable to predict future performance accurately, the reclamation planner nevertheless needs to adopt an approach that accommodates the inherent uncertainties of landscape development. Such an approach might include the following measures:

- patterning landscapes after natural analogues;
- designing the landscape with multiple lines of defence against certain failure models;
- designing robustness into the landscape, whereby the system becomes more stable with time;
- designing components and systems that are reliable and predictable;
- constructing ‘fire-breaks’ in 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 artificial materials such as pipes, gabions, fences etc.;

- releasing contaminants at acceptable levels over time rather than attempting to contain them forever.

SUSTAINABLE LANDSCAPE SOLUTIONS PATTERNED AFTER NATURAL ANALOGUES

The historical approach to configuring landscape for reclamation is to develop uniform slopes conforming to neat lines and grades. This lends itself to uniformity of design and construction but does not necessarily achieve the mine closure objectives of minimum erosion and long-term sustainability. Uniform landforms represent immature topography and are poised to evolve by accelerated erosion. In contrast, the development of a sustainable landscape for mine closure, involves the development of landforms that replicate natural landscapes. The replication of mature and relatively stable natural systems reduces the rate and risk of accelerated erosion. It also encourages replication of the self-healing erosion control systems that help preserve the stability of the natural analogue.

Examples of natural analogues for reclamation of mine-disturbed land are given below.

Mature (non-uniform) Topography

Uniform topography at tailings storage areas and mine waste-rock dumps is often incompatible with the goal of long-term sustainability. It is preferable to reconfigure the mine closure landscape to replicate mature topography (Fig. 2). This strategy acknowledges the evolutionary process of landscape development. Mature topography has already been subjected to the rapid erosion of its previous immature state and has developed to a state of relatively slow change. Mature topography is characterised by relatively short slope lengths and slopes that become more gentle as flow concentrates in the downslope direction. Flow paths are well defined in swales, which are deep enough to handle any extreme flood and to avoid spillage into adjacent swales or subbasins. Instead of uniform slopes, mature topography has variable slopes with hills and valleys. These serve to improve the aesthetic appearance, provide a wider range of habitats for wildlife and avoid the large surface flow rates typical of long, straight slopes.

Reduced Slope Length at Steep Slopes

Steep slopes may be 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 erodibility and infiltration capacity of the soil. Some areas, such as the sand-dunes near Lake Athabasca (Canada), have steep slopes and minimal plant cover but are not subject to surface erosion by water. The reason is that the sand-dunes are composed of coarse sand, which allows high infiltration. The infiltration rates are greater than maximum rainfall intensities. As a result, surface runoff and surface erosion by water is minimal. Slopes covered by dense grasses, which develop a thick root mass, are also 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 (cf. Nicolau and Asensio, this book).

Avoid Ponding on Terraces

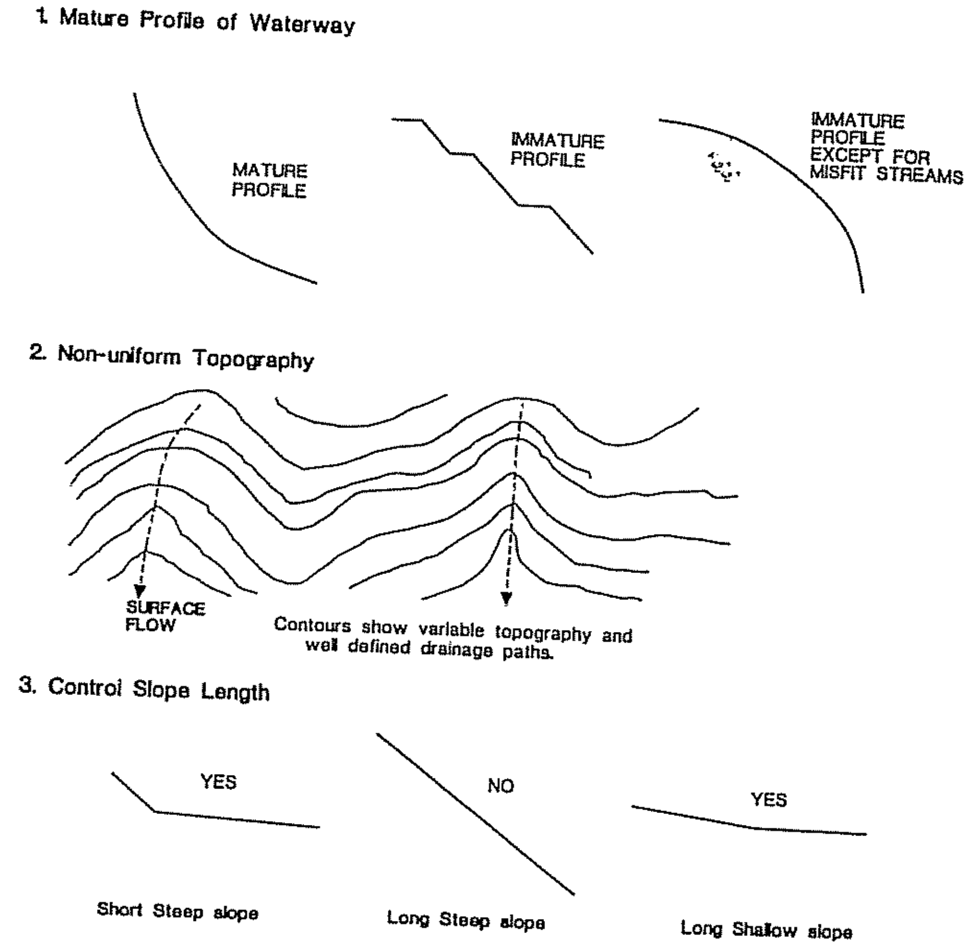
One common misunderstanding regarding erosion control is that terraces prevent erosion. Whereas terraces intercept surface runoff during low intensity storms, erosion can only be controlled if the accumulation of surface water does not exceed the storage capacity on the terrace or if the resultant spillage is properly controlled by a spillway structure. Whereas terraces can prevent erosion in the short-term during normal hydrologic events, they can 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 rice production areas. Terraces can cause accelerated erosion even during normal hydrologic events if they are improperly maintained. Terracing represents an immature topography and is not presented in nature as an erosion control mechanism.

Self-sustaining tailings and submerged waste-rock containment facilities can be developed if planned in advance of mine closure and integrated into the overall mine plan. Design criteria include shallow ponds located far from any dam embankment, a large spill channel cut into bedrock or set at a non-erodible slope and a wide rock barrier between the pond and the containment dam.

PASSIVE CHANNEL EROSION PROTECTION MEASURES

Passive erosion protection measures minimise the risk of accelerated erosion by suitable configuration of the landforms at mine-disturbed land. This is accomplished without structural systems such as riprap, drop structures, or rigid linings. Passive erosion protection systems avoid high-velocity flows and large discharges over steep slopes. Like natural drainage systems, passive erosion protection systems are compatible with the gradual evolution of natural landscape, which is characterised by low rates of erosion.

Passive erosion protection includes measures whereby the size of drainage basins is controlled to avoid large discharges in a single channel


1. Mature Profile of Waterway

2. Non-uniform Topography

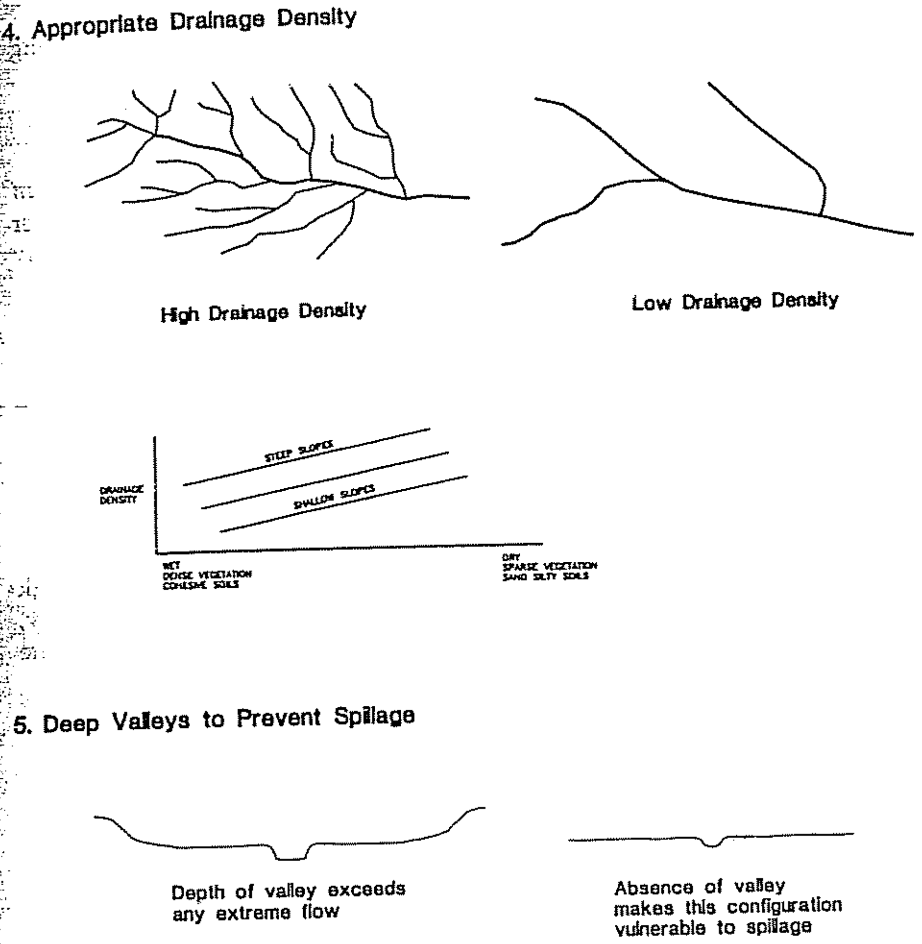
3. Control Slope Length

Fig. 2: Sustainable landscape patterned after natural analogues

on a steep slope. The use of cohesive soils mixed with gravel and cobbles beneath drainage courses provides for stream channel armouring and re-armouring in the event of large floods.

The characteristics of natural rivers provide ample guidance for the design of passive erosion protection systems at mine reclamation sites. However, the self-healing character of natural systems must be built into man-made channels by designers who appreciate the inherent stability of natural systems and who understand the geomorphological processes.

The resultant drainage systems, based on passive erosion control measures, will offer superior performance in the long run. The costs of such systems are not necessarily greater than the cost of conventional structural systems. Through appropriate planning, the costs of sustainable channels, which incorporate passive erosion control measures, may be less


4. Appropriate Drainage Density

5. Deep Valleys to Prevent Spillage

Fig. 2: *Contd.*

than those of conventional systems which are built with rigid structural erosion protection systems. Examples of passive erosion protection measures are given below.

Bouldery Ground Beneath Drainage Channels

Placement of waste rock or overburden material with high rock content beneath a drainage channel (see Fig. 4) 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 may not have to be repaired after extreme events such as the Probably Maximum Flood (PMF) or even the 100-year flood. The armour layer of natural streams is often non-erodible for events of 2- to 10-year recurrence and is subject to relatively small changes during more extreme events.

Suitable Drainage Density

The 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 (Schumm 1992, 1977). Drainage density can be qualitatively related to dependent parameters (Fig. 3).

Use of Regime Channels

Instead of providing channel armouring, the reclamation planner should design regime channels to replicate the dynamic character of natural channels. Some examples of natural channel features are given in Fig. 4. Channel geometry and pattern were selected from extensive data available from research by fluvial geomorphologists (Schumm 1977). Thus the planner has more than adequate data for selecting appropriate channel parameters to 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 resultant regime channels, which are patterned after natural channel characteristics, will exhibit equilibrium conditions, thereby avoiding progressive channel degradation or aggradation. Regime channels are capable of handling extreme events. Erosion control is not necessary because the channels are designed to be dynamic and accommodate erosion. Flow capacity can be achieved by building drainage channels in well-defined swales or small valleys, just like natural drainage systems.

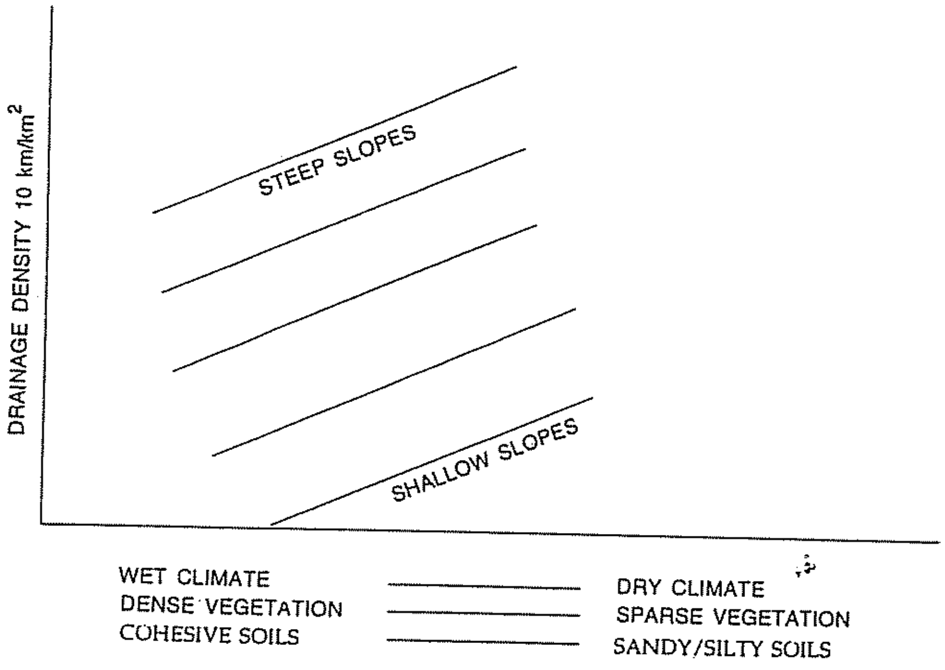


Fig. 3: Factors governing drainage density

Floodplains to Attenuate Flows

To reduce flow velocities, the planner may follow the example of natural systems wherein streams are flanked by floodplains, as illustrated on Fig. 4. The floodplains provide extra flow capacity and storage to attenuate the peak flood flow.

Littoral Zone Vegetation and Shoreline Armouring

If the end-pit lakes are small or shallow (i.e., less than 2 metres), it may be possible to protect the shoreline by littoral zone vegetation, following the pattern of similar conditions in the natural environment, as illustrated in Fig. 4. If the end-pit lakes are large and deep, then it will be necessary to provide a large source of coarse materials at the shoreline and inland from the shoreline. This approach allows a degree of shoreline recession, which exposes coarse material to armour the beach. The alternative, to provide a relatively thin layer of riprap shore protection, may not be sustainable because such rigid shore protection measures are subject to failure caused by ice, design event experiences, subsidence, lake level fluctuations and undermining.

A principle reclamation concept is that reclaimed landforms such as drainage channels will change over time and that no attempt should be made to resist such change. Instead, every attempt should be made to anticipate change so that systems can be designed to accommodate change. Anticipation of changes enables the reclamation planner to build robust systems with second and third lines of defence.

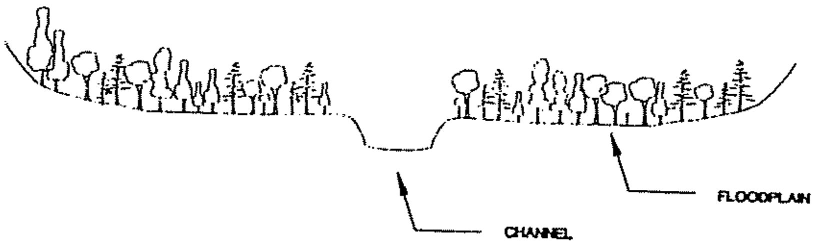
CONCLUSION

The development of geomorphically mature reclamation landforms and drainage systems can lead to improved sustainability and reduced long-term liability. Such systems are designed by replicating natural analogues and offer robust, self-healing capabilities similar to systems in the natural environment. This geomorphic approach should be used to develop permanent walk-away schemes and can also be used to reduce the liability of perpetual maintenance reclamation systems.

1. Use Regime Channels

WIDTH = *function of mean flow rate and bank materail*
DEPTH = *function of mean flow rate and bank material*
GRADIENT = function of flood discharge and sediment size.
MEANDER WAVELENGTH = *function of mean annual flood and bed/bunk material*
SINUOSITY = *function of bed and bank material*

2. Flood Plains to Reduce Velocity and Attenuate Flow

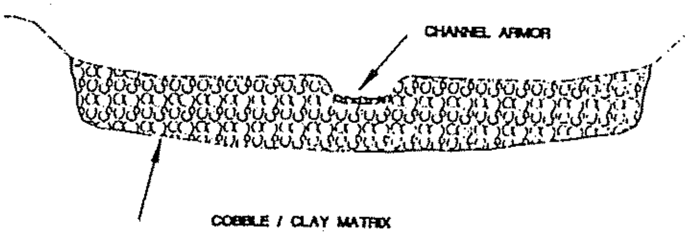


3. Meanders to Reduce Gradient

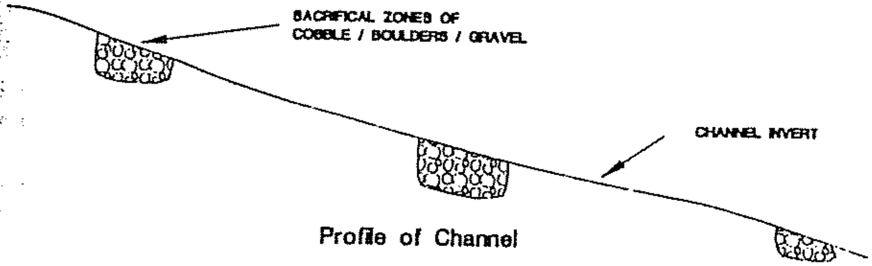
4. Lakes and Wetlands to Attenuate Floods

Fig. 4: Passive channel erosion protection measures (Geomorphic Approach)

5. Bouldery Ground Beneath Channels for Self-healing



6. Sacrificial Zones of Armoring Material



7. Lake Shoreline Protection by Littoral Vegetation

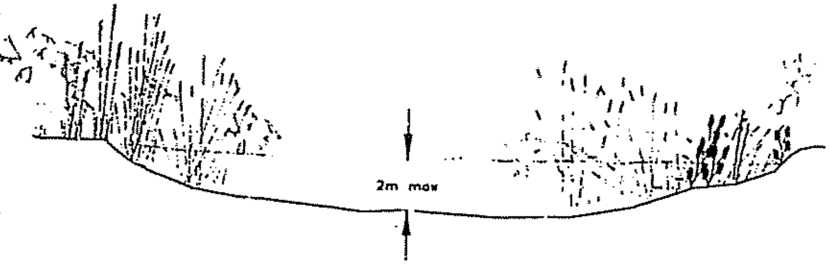


Fig. 4: *Contd.*

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A Strategy for Determining Acceptable Sediment Yield for Reclaimed Mine Lands

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P.G. Anderson

Abstract

This paper presents a procedure for determining acceptable sediment yield and includes an example for mine reclamation planning. In the interest of preserving or enhancing ecological integrity, landscape designers and regulators tend to establish highly restrictive criteria governing erosion at reclaimed mine lands. Some regulations call for non-erosive landscapes even though such criteria may be unachievable. This neglects the fact that all natural landscape is subject to erosion and that most natural river basins yield substantial quantities of sediment. Non-erodible landscapes are also undesirable in nature since the sediment process is a necessary element of long-term landscape sustainability (stability or evolution). Furthermore, an attempt to minimise sediment yield to negligible rates may not address the real impacts on aquatic habitats which should be mitigated, and may overlook the real ecological needs or natural basin characteristics. An approach is offered, based on a holistic evaluation of impacts in the determination of rational sediment yield criteria, relevant to site and regional conditions, for mine land reclamation. Examples are given, which show how sediment yield criteria are related to aquatic systems and natural background rates of sediment delivery.

INTRODUCTION

Sediment yield from disturbed land and suspended sediment concentrations need to be regulated to protect downstream receiving

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