Geomorphic Approach for Design of Sustainable Drainage Systems for Mineland Reclamation

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GEOMORPHIC APPROACH FOR DESIGN OF SUSTAINABLE DRAINAGE SYSTEMS FOR MINELAND RECLAMATION

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ABSTRACT: The historical approach to configuring landscape and drainage systems for reclamation is to develop uniform slopes conforming to neat lines and grades and to supply rigid, non-erodible drainage facilities, designed to handle a specific extreme event. 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 landscapes represent immature topography which is poised to cause accelerated erosion. In contrast, the recommended geomorphic approach to design of drainage systems and landscape for mine closure, would involve development of land forms and armouring processes which replicate natural landscape and natural drainage systems. Replication of natural systems reduces the risk of accelerated erosion and enables provision of self-healing erosion control systems. For example, limiting overland flow path lengths prevents gullying. The positioning of flow paths at the base of swales enables economical use of erosion protection materials. The use of cohesive soils mixed with gravel and cobbles beneath drainage courses provides for armouring with re-armouring in the event of large floods, similar to the natural environment. The development of non-uniform topography improves the aesthetics and improves wildlife habitat. An approach and procedure for design of landscape and drainage systems is presented with an example from a mine project in Alberta.
KEY TERMS: Natural analogue; sustainable drainage; natural systems; drainage criteria; mine closure; reclamation; mine water management.

INTRODUCTION

There is relatively little performance data available to aid engineers in the design of abandonment facilities for mine reclamation. The technology is in its infancy because modern reclamation standards are just a few years old. Any standards that have been developed have been applied to relatively few mine reclamation projects. Those that have been applied have been tested for only a short period of time.

The conventional approach to the design of a drainage system for mine reclamation is to comply with a set of verifiable criteria. This leaves a number of questions unanswered. What are the consequences of flood exceedances? What are the impacts of unanticipated events such as slope failure, debris jams, icing, sedimentation, channel aggradation, beaver dams, and in-channel vegetation? Will future human

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interference with the drainage scheme deteriorate the fragile regime? Without answers to these questions, the man-made drainage systems for mineland reclamation may not function satisfactorily over the long term.

Natural systems are also vulnerable to flood exceedances, unanticipated events and future human interference. However, in contrast to many man-made drainage systems, natural systems are often self-healing. Man-made drainage systems can also be made to be self-healing; however, this characteristic needs to be built into the drainage system by design. Normally, man-made channels are not self healing because of the fragile nature of disturbed mine landscape.

CONVENTIONAL PRACTICE

Current practice for design of drainage systems for mine closure and abandonment, varies across the country. Typically, drainage systems are designed to accommodate a flood of a specific design recurrence interval. Various design standards are applied. They range from the 100 year flood to the Probable Maximum Flood (PMF).

There are a number of deficiencies associated with the current practice in some jurisdictions. First of all, there should be well defined guidelines for design of drainage systems, which recognize the relative impacts of flood exceedances and failure of the drainage system. Different standards should be applied depending on the consequences of failure. This approach has merit because the consequences of eroding non-toxic material, such as might occur at a gravel waste dump, are much smaller than the consequences of eroding an impervious cover over toxic material such as nuclear or acid generating tailings.

A second deficiency of current practice is the absence of a self-healing mechanism. Often, when man-made channels fail due to overtopping, washout of erosion protection, or channel degradation, the failure leads to accelerated erosion and/or channel relocation. This may be unacceptable because of high sediment yield and loss of aquatic habitat resulting from the failure. These impacts are very severe within man-made channels in reclaimed mined-out areas where the underlying materials are highly erodible and or contain heavy metals or acid generating materials.

NATURAL PROCESSES

Natural drainage systems normally react much differently to flood exceedances and unanticipated occurrences, which disrupt the natural regime. The geomorphology of most natural channels situated in erodible materials, has produced floodplains alongside the channel. If the channel capacity is exceeded, the adjacent floodplain is inundated, offering a much larger cross sectional area for flow. The floodplain also serves to attenuate the inflow by providing flood storage. These characteristics of floodplains serve to significantly reduce flow velocities in natural channels.

Overtopping is rarely a serious matter in natural channels, since they are normally located in swales and at the bottom of valleys. The depth of the swales and valleys normally far exceed the depth of any conceivable flood event. As a result there is little risk of channel relocation to another swale or valley.

Another natural process which appears to accommodate unusual floods and other occurrences is the dynamic nature of the banks and bed. Instead of a rigid bed and bank composed of a rigid layer of erosion protection material (such as riprap), natural channels have a mobile bed composed of natural armour, which moves in response to extreme flood events. Natural channels are able to move laterally and vertically in response to changes in the river system. Certain large floods may wash out the armour layers which form on the beds of natural channels. However, subsequent flows will cause re-armouring of the bed through resupply of coarse material or by limited degradation of the channel bed. The net result is the re-establishment of the original stable regime.

A fourth process of natural drainage systems is the equilibrium of sediment supply and transport. Although, there is aggradation or degradation of the stream bed in natural channels, the process is normally very slow and thresholds exist which may reverse the trend from time to time. The natural system is relatively stable compared to man-made systems, because of its morphological history during which the channel has had opportunity to build a stable regime.

Other natural processes such as the formation of meanders and the development of cutoffs, illustrate the dynamic character of natural systems. Despite the sometimes high rates of change that may occur, such natural systems are considered to be sustainable and far superior to most man-made drainage systems.

PROPOSED APPROACH

The characteristics of natural systems provide ample guidance for the design of permanent man-made drainage systems at mine reclamation sites. However, the robust 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 processes.

Design of drainage systems by replication of natural systems is recommended as a superior design criteria for reclamation of mined-out areas. Regulators will need to accept the dynamic nature of such drainage channels. They also will need to accept the design of channels which are subject to controlled change, but which have a capability to accommodate unanticipated events and design flood exceedances without accelerated erosion or catastrophic change. Designers will need to learn the character of the natural drainage systems and apply fluvial geomorphic processes into their designs.

The resulting drainage systems, based on a natural analogue, will offer superior performance in the long term. The costs of such systems are not necessarily greater than for conventional man-made channels. Through appropriate planning, the cost of sustainable channels which replicate natural systems, may be less than that of conventional systems which are built with rigid erosion protection systems. These concepts are illustrated in the following case study which is based on reclamation design for a mine in Western Canada.

CASE STUDY - OILSANDS MINE

The Syncrude Canada Ltd. Mine (oilsands) in northern Alberta is situated in relatively flat terrain on a terrace above the Athabasca River valley, 40 km north of Fort McMurray, Alberta. Most of the natural channels on the mine site were irregular channels through muskeg, and were controlled by numerous beaver dams. Upstream sediment supply was relatively small.

Upon mine closure, there will be several very large sand disposal areas and overburden waste disposal areas, up to 40 m high and up to 40 km² in area. The abandonment topography will include some areas of significant relief at the edges of the disposal sites and other areas of relatively flat topography. The flat lying reclamation areas could be drained by channels set at a small slope to ensure non-erodible velocities for any flood, including the PMF. In order to replicate the original natural drainage systems at the minesite, these channels would be set in gentle swales. The resulting non-uniform landscape would provide definite drainage divides to prevent re-establishment of the drainage course at another location. This concept is illustrated in Figure 1.

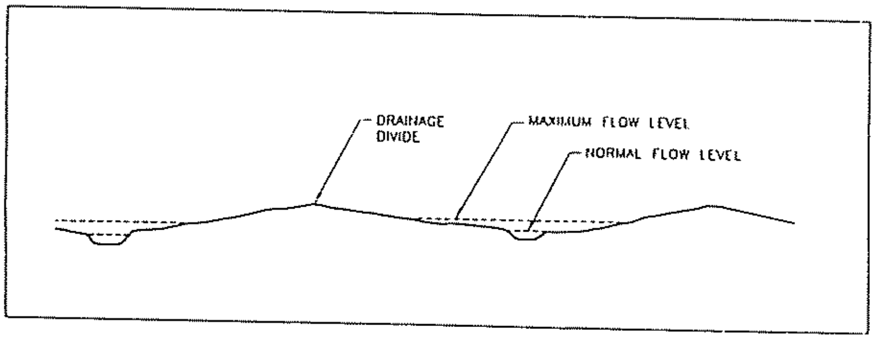

Figure 1. Non-uniform Topography and Well Defined Drainage Divides.

Overland runoff would be designed to drain towards the man-made channels without creating gullies. Erosion would be controlled by providing a suitable soil and vegetation cover, and by providing a suitable drainage density which limits the path length of the overland runoff. A local natural analogue is needed to determine the maximum path length. If this is not available for similar slopes, soils and vegetation, the designer will need to obtain guidance from literature for determining the required drainage density. This concept is illustrated in Figure 2.

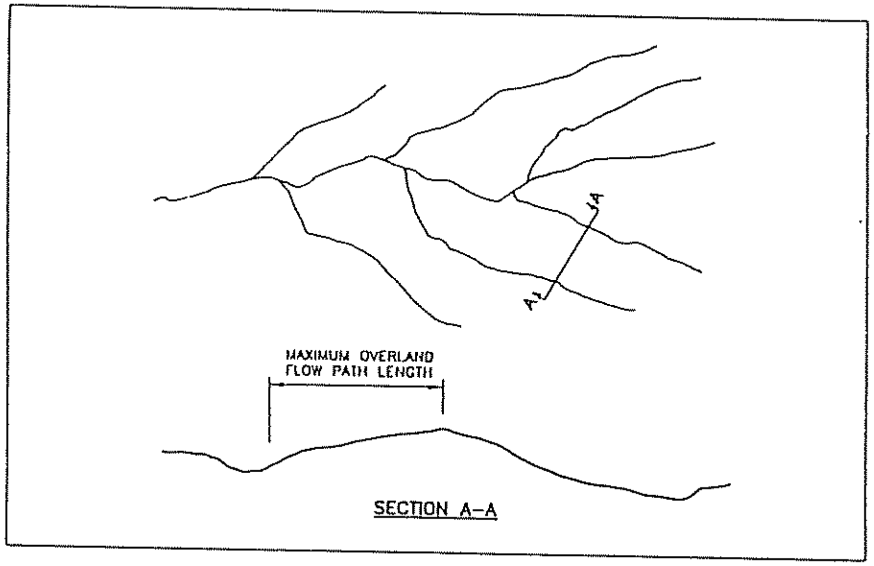

Figure 2. Drainage Density Required to Avoid Excessive Path Lengths for Overland Flow.

A third type of natural analogue can be provided for the main drainage channel. This channel could not be designed with non-erodible velocities because a relatively steep slope was required to convey catchment runoff from the terrace, down the escarpment to the Athabasca River. Several optional locations for this primary drainage channel were considered. In each case, the gradient was up to 1 percent which was much higher that the original natural drainage channel down to the Athabasca River. Without some form of erosion protection, this channel would be subject to extensive erosion because of the steep slope and because of the presence of mined-out sand at one location.

There are many similar conditions in the natural environment where steep gradients occur on natural channels. These offer a suitable natural analogue for the design of the main drainage channel. The recommended design replicated three natural process. Firstly, meandering was built into the design to minimize the channel gradient and thereby minimize the channel velocities. Secondly, a floodplain was provided to the design to enable overtopping of the channel banks and thereby minimize channel velocities during extreme floods. The total channel depth including floodplain would be at least 5 metres to prevent overtopping by beaver dams. Thirdly, the design called for the channel to be embedded in cobbly clay material which would allow for the development of multiple armour layers.

The channel would be lined with up to 5 metres of cobbly clay composed of 25 percent to 50 percent gravel and cobbles. The banks of the channel would be bounded laterally with up to 30 metres of the same material. The purpose was to supply enough gravel and cobbles to accommodate some movement of bed material, some erosion, occasional washout of an armour layer, and enough course material to re-armour the channel bed during repeated extreme flood events. This concept is illustrated on Figure 3.

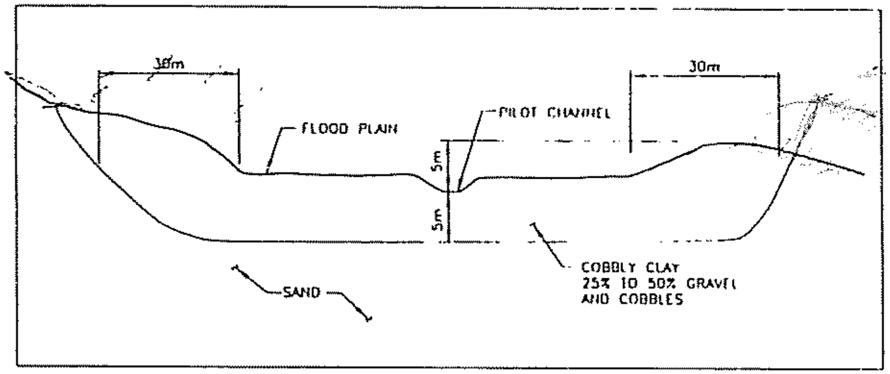

Figure 3. Cross Section of Meandering Man-made Channel.

Ongoing research by the mine will establish an estimate of longevity of this system by monitoring clay erodibility and computer modelling a synthetic series of climate and hydrologic conditions in which degradation and re-armouring is simulated.

This system is believed to be more robust than a rigid system of riprap erosion protection, even if it were designed for the PMF. It may also be less expensive because the cobbly clay material is a waste material of overburden stripping. With advance planning, it may be possible to place this material during mine operations at relatively low cost, as part of the waste disposal operation.

CONCLUSIONS

In the current regulatory environment, abandonment plans for mines, must provide a sustainable and self-healing drainage system which can perform over the long term without maintenance. This is a significant departure from the conventional approach of designing rigid, non-erodible drainage facilities on a uniform landscape. The preferred approach is considered to be cost effective; aesthetically pleasing and beneficial to the natural ecosystem because it is analogous to the pre-development natural environment. Ref: 990\abstract.geo

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