

Natural Approach to Mined Land Rehabilitation

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SUMMARY

A major challenge of open pit mine operations is to efficiently dump the overburden waste material in a cost effective way. The traditional approach is to pile the overburden material in a large pyramid shaped "dump". The advantages of this approach are that the haul distances to the dump are minimized and the perceived "footprint" of the waste material on the natural surroundings is minimized. However, the landforms created by this approach are subject to significant erosion. Rainfall events lead to the loss of topsoil, the development of incised gullies and water channels on the dump and, at times, slope failures. This soil erosion affects the downstream channels by increasing turbidity, salinity and mineral content and introducing excess sedimentation. Mining companies build structures such as rock drains, contour banks and sediment ponds to mitigate this problem. However, over time, mines have found that these approaches often do not work and require the mine to constantly maintain the dump and its drainage structures. Many consider waste dumps unsightly and have found that they can rarely be used for the same purposes that existed before mining (e.g. agriculture). In 2000 a new GeoFluv (Fluvial Geomorphic) approach was introduced to a BHP mine in the USA to address the problems of traditional waste dumps. GeoFluv uses hydrological principles to design stable, "natural" landscape forms. These landforms honor the basic principles of water flow and are therefore not subject to accelerated erosion. Using advanced CAD software, the GeoFluv approach can be easily applied to design a "stable" landscape and to calculate the cut/ fill balance and mass haul associated with the design. These designs can be built in the field using GPS-guided machinery. The resulting landscapes are stable, aesthetically pleasing and promote biodiversity of native flora and fauna. The new GeoFluv fluvial geomorphic approach can be applied to a wide range of land development and rehabilitation projects to provide well-engineered, stable, cost-efficient and aesthetically pleasing landforms that work with the environment.

1. INTRODUCTION

Open pit mines are developed to extract valuable minerals from the earth, by removing all of the 'overburden' materials that lie on top of the ore minerals to access the minerals themselves. The removal of overburden materials is carried out by a large range of earth moving equipment. Some of the materials are backfilled into the mining pit after the minerals have been extracted, but often there are also large "waste dumps" of overburden left on site adjacent to the pit after mining operations.

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A common form of waste dump that results from the operations is a 'flat topped' pyramid. Dump trucks are sent to the top of the waste dump and pile up the dirt in stages (or lifts). Environmental managers at the mine are involved with the design, shape and construction of the dump. Traditionally, their main concern during the design phase is the size and location of the 'footprint' of the dump and the slope angle of the dump sides.

Once the mining operation is complete, the environmental engineers concentrate their rehabilitation efforts on controlling the waste dump from changing and deteriorating over time. They are concerned that any water run-off from the waste dump will erode the dump, carry suspended sediment into local creeks and streams – reducing their water quality through increased turbidity. In some cases, there is concern that the parts of the dump itself may collapse in times of severe rainfall and impact mining and community infrastructure – buildings, roads etc. The environmental rehabilitation group at the mine is tasked with protecting runoff water quality from the dump. Runoff is often routed using a series of drop structures (eg. rock drains), contour banks, concrete channels and retention ponds. The rehabilitation also includes efforts to re-vegetate the site as soon as practicable to consolidate the slopes and minimize erosion and support post-rehabilitation land uses.

The traditional approaches to mine rehabilitation have been practiced for many years and are accepted within the industry. These approaches to rehabilitation are discussed in the first section of this paper.

The science of Fluvial Geomorphology studies the action of flowing water and how it influences the shapes of landforms. The relationship between climatic conditions (eg. rainfall), geology and soils and also topography are studied to understand the relationships between catchment area, rainfall, water discharge and the varying stream characteristics of stream pattern, stream slope, meander patterns, ridgeline profiles, channel cross-sectional profiles, etc. Over the last 30-40 years these relationships have been studied and documented (Dunne and Leopold, 1978) resulting in a number of stream classification systems being developed (Breirley and Fryers, 2000, Rosgen, 1996).

All of these studies indicate that natural streams develop with predictable characteristics and relationships. Upland streams are seen to have greater slopes (>4%) and often have a very slight meander pattern. As streams and tributaries join together, the meander pattern becomes more pronounced, the slope flattens, discharge increases and the cross-sectional profiles become more pronounced. It also is noted that mature landforms generally display a longitudinal profile that changes from convex to concave.

The waste dumps constructed at mine sites display landform characteristics that are typical of 'youthful', i.e., highly subject to erosion, natural landforms. In nature, one does not see any long, constant-gradient slopes, streams flowing parallel to contours, terraces, or 'drop structures' in 'mature', (i.e., low erosion-rate) stable landforms.

Nicholas Bugosh is a trained hydrologist who was employed as Senior Hydrologist at the BHP Billiton La Plata open pit coal mine in the USA. He understood that traditional methods of mine rehabilitation were costly and required long term maintenance. In order to address these issues, Bugosh developed the “GeoFluv” approach to landform design.

Bugosh’s premise was that if landscapes could be built in the same way that nature would eventually form them, they would be self-sustaining and functional. This would obviate the need for man-made contour terraces and drop structures, and would result in a “working landscape” that would provide an excellent platform for re-vegetation and habitat re-establishment processes.

This paper describes the ‘GeoFluv’ approach and the implications that it has on the development and building of waste dumps. An example of the La Plata waste dump (New Mexico, USA) is described – including construction methodology and the results obtained.

The final section of this paper will describe some of the challenges in introducing this new approach to the mining industry outside of the U.S.A. – including the paradigm shift in the entire approach to rehabilitation, implications to the construction and development of waste dumps, the benefits of using to GPS guided earthmoving and possible updates to regulatory and environmental requirements for mining rehabilitation.

2. TRADITIONAL METHODOLOGY FOR MINING REHABILITATION

2.1 Current Rehabilitation Approach

Traditional approaches to land rehabilitation have been developed to address mining goals (minimizing haul distances, optimizing earth movement, working within the lease boundary, and minimizing impact on the surrounding land holdings.), regulatory goals (including meeting environmental standards) and community expectations for the use of the land after mining operations have been completed. In traditional practice, large “pyramid” shaped waste dumps are built adjacent to the working pit. Some of the guiding principles in rehabilitation include :

2.1.1 Minimizing the “footprint” of the operations.

Currently the term ‘footprint’ defines the area of the waste dump. After the mining operation, this land is considered less productive agricultural land – even after it has been rehabilitated. The current ideal is to keep the footprint as small as possible – in an effort to fit the waste material in the smallest area. The shape of the waste dumps usually resembles a flat-topped pyramid, as this is considered the most practical way to hold the most material in a small area.

2.1.2 Optimize Earth moving – reduce costs

In order to optimize earth moving operations, it is cost effective to immediately move the overburden as short a distance as possible to the dump the first time. Double

handling of overburden material is an expensive operation, and is to be avoided. The current waste dump configurations often include haul roads from the pit to the dump and the material is dropped at the top of the dump. Bulldozers are used to push the waste material in the final designed form.

2.1.3 Meet Environmental Regulations

Regulatory authorities require that mines meet certain environmental requirements including, stability of the waste dump, some height and size requirements, and the quality of the water running off the site. Long term stability of the waste dump is a critical issue and requires that erosion of the waste dump is tightly controlled.

In order to minimize the effects of running water on the waste dump, mines implement a number of common tools to try and remove water from the waste dump as quickly as possible.

- **Routing Water Away**
A common practice for controlling erosion of the rehabilitated area is by routing water away as quickly as possible. The methods used to route water away from the waste “pyramid” structures that have been built can involve a number of techniques including the use of gradient terraces (contour banks), concrete channels, and drop structures (rock drains) which transfer water from one level to another while attempting to minimize erosion. These structures are costly to build and need constant long-term maintenance. Contour banks often fill with silt, causing occasional ‘overflow events’. Concrete channels need to be cleaned out. During a heavy storm, water will undermine and flow around the rock drains – requiring immediate attention and repair.
- **Retention Ponds**
Mines currently use retention ponds to limit water flow off the site. These ponds are designed to retain ‘polluted’ or highly saline water on site for either treatment or further dilution. The construction of retention ponds enables the mine to control the flow of mineral elements and excess nutrients into the environment.
- **Re-Vegetate the Dump**
Once the waste dumps are constructed, the slopes are planted with local vegetation to help stabilize the banks. As the dump consists of unnaturally long, single gradient slopes oriented in the same direction (slope aspect), they limit potential biodiversity that can be influenced by subtle changes in aspect and slope.

The waste dumps resulting from meeting these criteria can be strange indeed. Even though the dump may meet the criteria outlined above, they often require constant maintenance to perform as designed, and also many find them to be not aesthetically pleasing.



Example of a Traditional Waste Dump
(photograph courtesy of Steve Kite)

2.2 Limitations of the current Rehabilitation Approach

Although these waste dumps meet the mine's short term goals of optimizing earth moving and reducing costs, and meet the local regulatory requirements for slope angle and stability, their longer term legacy can be costly.

Regulators have found that the dumps often start to erode in heavy rainstorms and that the water running off the sites is turbid and affects the quality of the water in local rivers and streams. The mine therefore is required to undertake costly, long-term maintenance on all the water routing structures on the dump to satisfy regulatory requirements such as minimizing erosion and meeting water quality standards.

Land owners have found that the rehabilitated land can often not be used for pre-mine purposes – for example, land that was once used for agriculture is no longer available. The un-natural long, constant-gradient slopes of the dump do not provide an ideal platform to establish biodiversity, which often varies dependent on aspect and slope.

The basic underlying issue with the current mine rehabilitation approach, is that the landforms that have been developed are artificial and do not comply with **nature's** laws. If the landforms were subject to a thousand years of local rainfall, they would change in shape until they stabilized to a natural form.

By applying the principles of fluvial geomorphology and understanding the characteristics of how water flows in different conditions, Bugosh developed the GeoFluv approach to land rehabilitation.

3. THE GEOFLUV APPROACH

The GeoFluv approach is based on fluvial geomorphic principles that describe how landscapes function and operate. This section of the paper reviews the fluvial geomorphic principles upon which the software is based, discusses how the design is created and the role of mine operations in construction and building of the waste dump

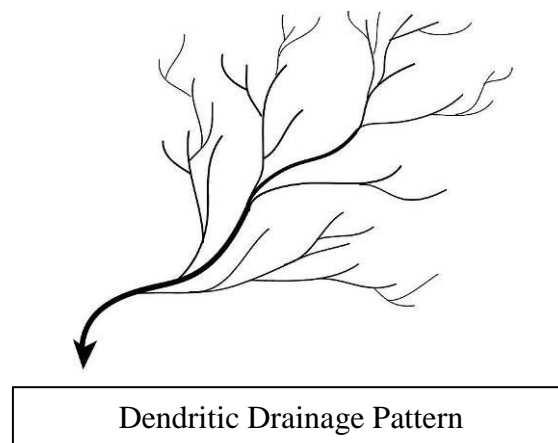
3.1 Hydrological Connections

Fluvial Geomorphologic studies over the last 30-40 years have improved quantification of how landscapes develop naturally through the power and force of water movement. It has been found that landscapes continue to develop naturally – with ongoing imperceptible levels of erosion continuing to move sediment from the uplands through the landscape and into the sea.

A concept of balance has been established between the amount and size of sediment being transported relative to the amount of water discharge and slope of the discharge. (Lane, 1955) If any of the parameters change (eg. amount of sediment, size of sediment, slope of ground and amount of discharge) the volume of sediment will change and cause the stream bed to aggrade or degrade.

3.1.1 Drainage Pattern

The drainage pattern of any stream system is closely related to the geology of the area. A common drainage pattern that develops in unconsolidated materials is a dendritic pattern. As most land rehabilitation uses unconsolidated materials, the GeoFluv approach assumes that the resulting drainage pattern will be dendritic



The drainage density defines the length of channels required per area unit to properly drain the site of the runoff water. If there is not enough length, water will naturally extend channel length until it is sufficient. It is often observed in earthworks construction that when there are not enough drainage channels for the water to drain off, that embankments are breached and new channels form.



Examples of a water extending channel length on constructed landforms
(photograph courtesy of Nicholas Bugosh)

Within the network of channels that form within the drainage pattern, it is also observed that as the channels move from the uplands to the final drainage point, they meet at stream junctions. The slope of either stream entering the stream junction is the same in stable channels.

As the tributaries meet and join, the characteristics of the channel changes to accommodate increased discharge. The slopes of the channels flatten as the water flows from the uplands to the valley bottoms. As the discharge increases, the subtle meander patterns found in the upper reaches become larger and well defined. The relationships between sinuosity (flow length/straight valley length), radius of curvature, meander beltwidth are now much better understood and can be observed on the valley floors of most large rivers.

3.1.2 Ridge Line Longitudinal Profile

Ridgelines in mature landscapes show a pattern of having a convex curve at the top of the ridgeline that transition into a concave curve towards the base



Examples of Convex to
Concave shape
transformations in nature

(photograph courtesy of
Nicholas Bugosh)

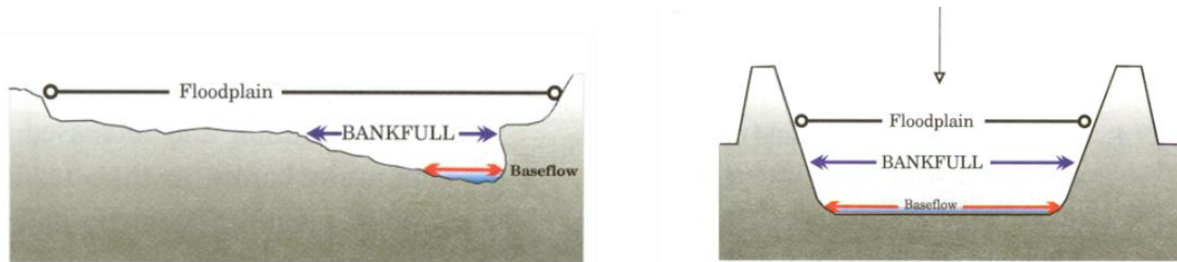


The transition from convex to concave slopes can be explained as follows. As rain falls on top of a ridgeline it may lay on the surface and have very little erosional force. As water accumulates, however, it starts to flow downhill and develop more erosive energy. When the erosive energy is great enough to dislodge and transport sediment, it carries the sediment down the slope until the flatter valley floor abruptly decreases the available transport energy and the sediment is deposited. The consequent adjustment in slope profile is that the slope is steepest in the upper portion where the least amount of water is present and the slope is flattest in the lower portion where the greatest amount of water is present. The transition point from a convex to a concave slope occurs at the point where water starts to flow and form drainage channels.

It is interesting to note the difference between these naturally occurring ridge line profiles and the long, constant-gradient slopes that are constructed in mine waste dumps. The traditional waste dump has a large surface area at its top that accumulates erosive water energy and then drains that greater volume of water over a steep constant-gradient slope, whereas the natural profile is the exact opposite, having a small area at the top to minimize the erosive force at the top end where the slope is steepest and having a flatter slope near the bottom to minimize erosive force there where the volume of water is greatest. It seems self-evident that as water accumulates and starts to flow off the top of a waste dump that it will apply the same erosional forces to the dump as it would in nature – and that over time a convex to concave profile will be created.

3.1.3 Channel Cross Section Profile

A critical component on any channel is the cross-sectional profile. The cross-sectional profile of all natural streams aids the stability of sediment transport in variable rainfall conditions.



Stream and Channel Cross Section – Floodplain, Bankfull Flow, Baseflow
(Rosgen, 1996)

The natural stream cross-sectional profile shown in the figure above can be seen to adapt to a range of flow conditions. With small flows, the stream is concentrated in a narrow channel, moving sediment along the channel bottom. During bankfull flows, the channel is expanded to carry more water and hence more sediment. In times of flood, the water flows into the floodplain, over a significantly expanded floodway.

The significance of the channel cross-sectional profile is apparent when considering “designed” channels that are sometimes used in channel straightening and flood mitigation. Upon inspection of this channel, it is clear that the channel width and shape does not change much relative to flow. In low flow events, the water in the channel does not have the energy to move sediment through the system. In these cases, sediment builds up until it has to eventually be cleaned out by earth moving machines.

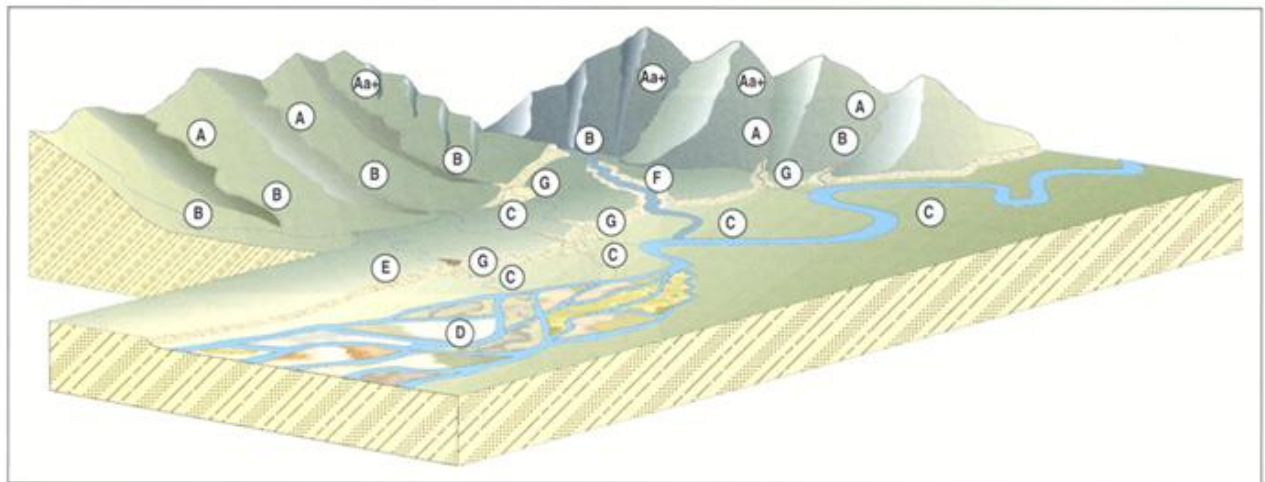
In times of bankfull flows, the channel may operate correctly, where sediment is moved along the channel by the energy of the water. In times of flood, all the water is contained inside the channel, and its energy cannot dissipate across a floodplain.

3.1.4 Channel Classification and Location

A number of researchers (Rosgen, 1996, Brierley & Fryers, 2000) have developed classification schemes to describe the basic characteristics of different stream and river types. These schemes break streams into different categories – based on slope, sinuosity, width to depth ratio, entrenchment and some landform characteristics – bedrock, soils etc.

Stream types will vary with landscape and location. In nature, there is not a “one size fits all” approach. Each stream type is suitable for its own location. Stream types that are suitable in the upper reaches of a catchment may have steeper slopes, less discharge and less sinuosity than the larger, meandering streams and rivers found in the valley bottoms.

The diagram below indicates the different stream classifications proposed by Rosgen (1996) and how they would expect to be located in the landscape.



Stream Classifications and their relevant locations in the landscape
(Rosgen, 1996)

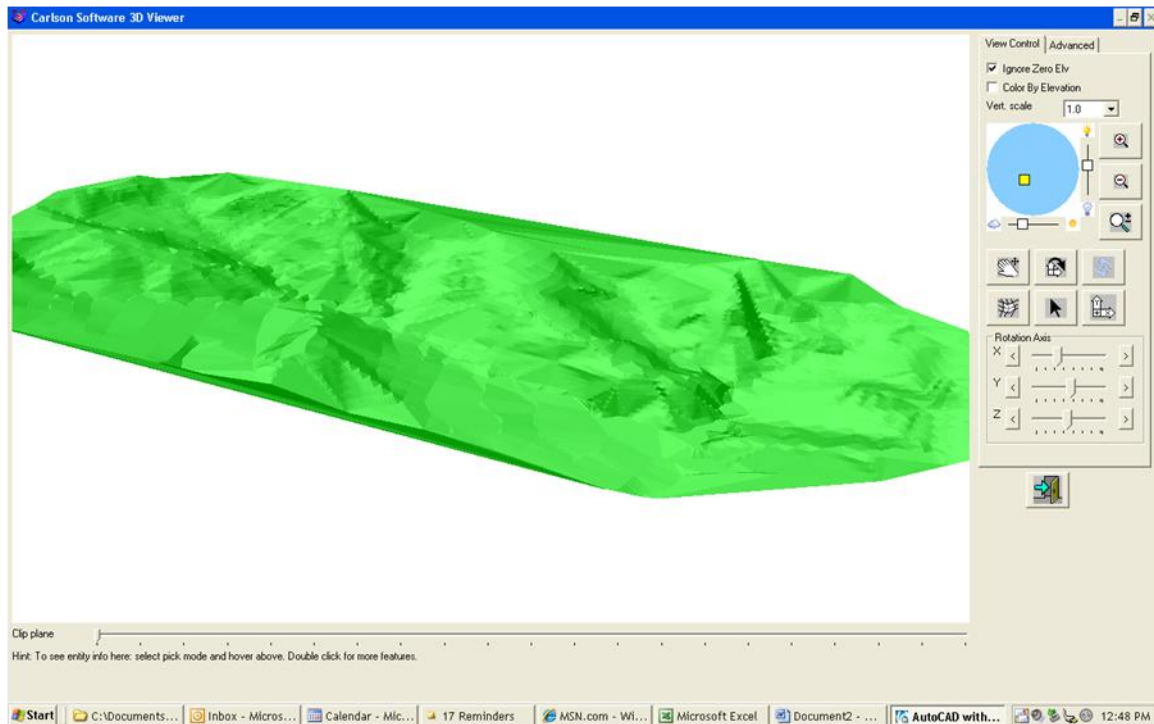
3.2 Applying the GeoFluv Principles

The GeoFluv approach incorporates the natural principles described above for stream channels and uplands and combines them into an integrated, functional landform using a Computer Aided Drafting (CAD) package, so they can be easily applied to the local area.

The GeoFluv approach assumes that rehabilitation is taking place with unconsolidated materials which would eventually form into mature landscapes over time. By inspecting and studying other mature landscapes in the vicinity of the rehabilitation site, key measurements that describe the landforms can be taken for use as input parameters to the design software. The information required as inputs to the software include drainage density, upland channel reach length and ridge to head of channel distances. These inputs allow the GeoFluv algorithms to design a landscape with the necessary number of channels with appropriate longitudinal and cross sectional profiles to enable the water to drain off naturally.

In addition to these local parameters the GeoFluv approach requires information about the elevation of the local drainage point, the slope of the channel at that point as well as some information regarding local rainfall and run off events.

To calculate a design, the operator merely has to define a boundary of the project area, draw in an approximate number of channels to meet drainage density requirements, provide a model of the current existing surface (or future designed surface), and the software will create a landform design that honors all the basic fluvial geomorphic principals that have been outlined above.



CAD output of a GeoFluv Design

Once a draft design is complete, the operator can display the amount of cut and fill required to balance the site and also can calculate mass haul diagrams.

As the CAD program is can quickly calculate a landform design, it is common practice to create a number of designs for the same project. This enable the designer to inspect and compare different approaches to the rehabilitation to find a design solution that optimizes cut and fill, and mass haul. The resulting GeoFluv landform design is not only a functional landform that is naturally stable against erosion, but is also economical to construct.

3.3 Machine Guidance

Once the design is complete, the design files can be surveyed and staked-out in the field or transferred to GPS guided earthmoving equipment that enables operators to easily be able to

build complex landforms, without the requirement for surveyors to set out masses of grade stakes.

A range of earth moving equipment has been used on the range of mines that have adopted the GeoFluv approach for rehabilitation – including the use of drag lines, shovels and loaders with dump trucks, excavators, backhoes, and bulldozers.

Ideally the rehabilitation plan can be completed before the mining operations commence – which enables the rehabilitated landform is built as the overburden is removed. Efficient and timely placement of the overburden material provides the most cost-efficient way of creating the final designed landforms and saves double handling the material.

4. RESULTS IN THE FIELD

Many Mine sites, landfills, quarries and construction sites have adopted the GeoFluv approach to their rehabilitation. One of the first examples of applying GeoFluv principles has occurred at the La Plata mine.

4.1 La Plata, BHP New Mexico USA

The La Plata Mine is located in northwestern New Mexico contiguous to the Colorado border. Elevations at the mine range from approximately 1,795 to 1,892 m. The annual precipitation is between 30.5 and 35.6 cm. The soils are thin and sandy with bedrock cropping out regularly. The vegetation is sparse, with bunch grasses, some forbes, and stands of pinyon pine and juniper. Together these elements comprise a high, semi-arid terrain that is highly erosive.

The GeoFluv approach to rehabilitation was adopted by the La Plata mine in 2000 and applied to over 890 ha of mined land. The photos below show some of the landforms that have been created using the GeoFluv approach and describe how they have responded to heavy storm activity.

The figure below shows a subwatershed with spoil graded to GeoFluv design before November of 2003 and any topsoil application. Close inspection will reveal construction equipment markings on the slopes, but there is no rilling or erosion. In the image, the landform has no topsoil, no vegetation, and no artificial erosion controls. The top of the ridge is 1,832 m elevation. Significantly, the image was taken in January 2005, after the site endured the 2003/2004 snowmelts, 2004 monsoon rains, and the 2004/2005 snowmelts.



La Plata Mine Northgate North Sub-watershed in January 2005

In 2005 this 15ha site had been constructed and topsoil had been placed. Soon after the placement of the topsoil, a 6-hr precipitation event was measured at close to the estimated 100-yr event (i.e., 69 mm). No erosion maintenance work was prescribed by the Mining and Minerals Division after this storm. The site staff reported that samples of runoff that were collected in the reclaimed channels above the sediment control ponds met National Pollutant Discharge Elimination System discharge requirements (Clark, 2008).

A picture of the same site is shown below. This picture was taken in mid-September of 2006 following the extreme July storm event. It is the same subwatershed as shown above, but after the application of topsoil and seeding, and is typical of the reclamation landform response to the >100-yr recurrence interval storm. The erosion monitoring after this extreme storm event documented that the fluvial geomorphic landform performed its functions as designed and found only two areas needing repair, both believed to be attributable to improper construction.



La Plata Mine Northgate North Sub-watershed in September 2006

Environmental monitoring of the rehabilitated lands at the La Plata mine indicate the success of the GeoFluv fluvial geomorphic landform design method used since 2000. Erosion monitoring indicated that the landforms were stable. The 2007 snapshot water quality monitoring suggests that the fluvial geomorphic reclamation runoff water quality may be equal to (if not better than) adjacent native lands.

The La Plata mine rehabilitation has won USA Mining Reclamation awards and is well recognized as a model for future rehabilitation work. This is an impressive achievement in what is arguably one of the most erosive environments in the continental United States.

5. CHALLENGES FOR THE FUTURE

The GeoFluv approach provides a new way and methodology for rehabilitating mined lands. It is a new approach that challenges mining engineers and regulators to consider alternative ways of rehabilitation.

5.1 Mining Engineers' Acceptance

Mining engineers understand the costs involved in rehabilitating waste dumps and the long term maintenance costs involved. Many have seen contour banks breached and rock drains undermined and washed away.

Experience has shown that when mine waste dumps have been designed and built using fluvial geomorphic principles that the cost of construction is similar to building waste dumps the traditional way. GeoFluv designed dumps, however, have been found not to require long term maintenance, saving costs in the long term.

Adoption of the GeoFluv method works best when all members of the mine design team understand the principles behind and the philosophy of GeoFluv, so that they design correctly and build it to tight tolerances. All members of the team need to be involved, including the bulldozer drivers who are often responsible for building the landform shape.

As the GeoFluv approach is a new way of designing and constructing waste dumps, training on the approach and support of rehabilitation activities is appropriate at the initial stages of implementation.

5.2 Regulators Acceptance

The GeoFluv approach provides regulators with an alternative methodology for mine rehabilitation that may affect mine plan approval. Various attributes of traditional waste dump may be reviewed including the footprint of the waste dump, the requirement and necessity of retention ponds, water quality run-off standards and the usability of the rehabilitated lands. For instance, if it is found that the rehabilitated land could be used for the same pre-mining purposes (eg. Agriculture), consideration could be given to change the ‘footprint’ of the mine.

6. CONCLUSION

The GeoFluv approach uses natural principles to design landforms for rehabilitation – to provide a superior result. The landforms can be constructed using GPS guided earth moving machinery. Landforms that have been built to GeoFluv designs have proved to be stable and maintenance free. The GeoFluv approach has proven to be cost-effective

The GeoFluv approach has been well accepted in the USA and has won international awards and prizes for rehabilitation. A key issue is that the rehabilitated land functions and looks like a natural landscape, is not in danger of eroding or slumping, enables pre-mine land use to continue after the mining operation on the rehabilitated land and provides a better platform for improved water quality and for the re-establishment local flora and fauna.

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BIOGRAPHICAL NOTES

Rod Eckels is an Australian surveyor who has been involved in GPS surveying since 1984. From 1987 -2006 Rod worked for Leica GeoSystems in a range of training, sales, support and management roles. Rod met Nicholas Bugosh in 2003 working on mine reclamation activities at the La Plata mine, New Mexico, USA. At La Plata, Nicholas was applying GeoFluv principles to the reclamation design and Leica was providing the Machine Guidance capability. Rod saw that the GeoFluv solution for landform design combined with the new capabilities of Machine Control provided an excellent solution for a long standing reclamation problem.

Nicholas Bugosh is the inventor of GeoFluv - a new approach to land grading that returns disturbed lands to natural function and appearance. Nicholas is a hydrologist who has spent many years studying the movement of water and how it influences the shapes of the landscape. Nicholas developed a methodology to design stable landforms in any region of the earth using the natural relationships that occur in nature and using local input design parameters based on measurements of essential landscape features of nearby “natural” land.

The result of GeoFluv processing is to design a natural a landscape that will convey runoff water the way a natural landform would.

In 2009, Nicholas formed the company “GeoFluv” to provide training, coaching, and consulting services in this innovative landform design method. The GeoFluv approach forms the heart of the Carlson Software Natural Regrade module that was released in 2005. Nicholas is also presently the GeoFluv™ Technical Director for Carlson Software.

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