OVERVIEW OF BEST PRACTICES FOR SURFACE EROSION PROTECTION AND SEDIMENT CONTROL FOR THE DEVELOPMENT PHASE OF SURFACE MINING FOR COAL IN NORTHEAST BRITISH COLUMBIA

M. Sloat, AAg., CPESC
R.J. Redden, R.P.Bio., A.Sc.T., CPESC

EDI Environmental Dynamics Inc.
4722 Continental Way
Prince George, B.C. V2N 5S5

ABSTRACT

Planning for surface erosion protection and sediment control for the development phase of recently developed surface coal mines in northeast BC has become an important part of the environmental management systems for these projects. Development of a surface mine involves significant land disturbance that typically results in increased rates of erosion and sedimentation. Planning to mitigate this impact must be proactive and integrated. The primary components of proactive planning for surface erosion protection and sediment control are completing assessments of soils and conducting overview hydrology assessments of potential surface and near-surface seepage areas. This information can be used to identify areas of higher risk for erosion and sediment generation and can be used to design a mine development plan that avoids or minimizes development of such areas if possible. Where development is unavoidable, this information can be used to design effective best practices for mitigating potential impacts resulting from a proposed mine development activity. Approaches for planning, developing, and implementing effective best practices for surface erosion protection and sediment control are presented in this paper. Examples of on the ground best practices are also provided.

INTRODUCTION

This paper provides an overview of best practices for surface erosion protection and sediment control for implementation during the development of surface coal mines in northeast BC. Development of a surface coal mine potentially involves significant land disturbance resulting in increased rates of erosion and sedimentation. A primary objective of erosion protection and sediment control for the development phase is to mitigate the effects of this land disturbance through a process that includes the following components: 1) completing soil and surface / near surface hydrology assessments and integrating this information into the mine development planning and design process so as to avoid higher risk areas if possible, 2) as an output of this process, 2a) drainage management to divert offsite drainage safely around or over the areas of disturbance or sensitive soils, and 2b) developing effective best practices for surface erosion protection and sediment control to mitigate site and phase specific mine development activities, and 3) ensuring processes are in place to implement these best practices in an effective manner. By this approach, integrating the results of soil and hydrology surveys into a proactive mine development planning process is considered a fundamental best practice for mitigating land disturbance associated with surface mining.

While this paper draws mostly from experiences gained working on recently developed coal mine projects in northeast BC, the intent of this paper is to emphasize the importance of proactive and integrated mine development planning and to identify best practices for erosion protection and sediment control that are applicable to a variety of mining operations. In addition, permanent erosion protection and reducing suspended sediment levels to near pre-disturbance levels are important objectives for mine reclamation. Implementing effective erosion protection and sediment control during the mine development phase also contributes to these broader objectives. In this context, planning for and implementing erosion protection and sediment control during the development phase of a surface mine is viewed as part of a larger system that links erosion and sediment control objectives through the development, operations, and reclamation phases of mining.

PLANNING FOR EFFECTIVE SURFACE EROSION PROTECTION AND SEDIMENT CONTROL

The Importance of Proactive and Integrated Planning

Implementation of effective erosion protection and sediment control requires proactive and integrated planning, and is considered a 'best practice' in and of its self. Collecting baseline environmental information is a primary component of this approach. For surface erosion protection and sediment control, two types of assessments are critical: soil surveys and overview surface and near-surface hydrology studies. A soil survey, based on colours and other properties, indicates the height of the water table during other, wetter periods of the year and is required to identify the spatial extent of different types of soils, especially those most erodible. Surface and near-surface hydrology studies can provide at least a basic knowledge of where surface drainage will concentrate or may emerge as surface runoff when the landscape is disturbed. Ideally, this information is integrated with mine design and development planning to identify areas of higher risk for surface erosion and sedimentation based on proposed mine development activities. More specifically, risk assessment in this context identifies where sensitive areas are located and considers the probability that these areas will be significantly impacted by erosion and sediment generation. Sensitive areas are characterized by the erodibility of the soils, the potential presence of surface and significant sub-surface seepage, and the value of adjacent aquatic habitat. A policy of avoidance (i.e. development of the mine and mine infrastructure in a manner that avoids higher risk areas wherever possible) becomes the first priority. The second priority is to design and implement effective drainage management and surface erosion protection and sediment control practices for mitigating potential impacts resulting from the proposed development plan for the mine.

Proactive and *integrated* are the two terms used to describe the planning process required for implementation of effective erosion protection and sediment control in this context. *Proactive* refers to the collection of soils and surface hydrology data and the use of these data to develop mine development plans that focus on avoidance of higher risk areas where possible and design of best practices for mitigation prior to commencing construction activities. *Integrated* refers to the involvement of professionals from all relevant disciplines to assist with developing a comprehensive mine development plan. Relevant professionals could include (but not be limited to) engineers from various disciplines, hydrologists, biologists, soil scientist and professionals in erosion and sediment control.

Regulatory Context

Planning for erosion protection and sediment control during the development phase of surface mines has become an integral part of project management systems implemented by mining proponents. This type of planning typically takes two forms. The first consists of a detailed overview of all proposed activities associated with development of a mine project and proposed measures for mitigating potential impacts resulting from surface erosion and sedimentation. This component supports the process for obtaining an Environmental Certificate as per the *British Columbia Environmental Assessment Act*. Using assessments to identify higher risk areas for erosion can be in an important component of this type of planning. More detailed activity and or site specific plans for erosion protection and sediment control in support of permitting for effluent discharge is the second form.

Recent Experiences

Our experiences working on some of the recently developed surface coal mines in northeastern BC have mostly been gained through planning erosion and sediment control mitigation based on existing mine development plans. In this context, planning for erosion protection and sediment control typically begins after baseline data documenting environmental conditions has been collected (i.e. information for soils and surficial geology, topography mapping, aquatic ecosystem inventories) and preliminary development plans that extend over the life of the mine have been developed. Planning at this stage enables identification of sensitive areas where highly erodible soils or valued aquatic features are present. This in turn facilitates design of measures to mitigate for increased rates of erosion and sedimentation potentially caused by specific mine development activities adjacent to these areas.

Working closely with engineers and environmental staff of the proponent has been a critical part of this planning process. Proponent staff often have critical knowledge with regards to how a specific construction activity or development phase will be completed. Often this information is not readily conveyed in the mine development plan. For example, a diagram showing the location of diversion and collector ditches and sediment ponds may or may not detail how the different segments will be accessed by heavy equipment or what construction sequence would be most effective for minimizing erosion. Thus, a result of integrated planning is often the identification of such issues with proponent staff and the use of this information for designing effective erosion and sediment control measures adapted to the specific activity and the condition of the site. In many instances, avoidance of a higher risk area when developing access to a specific site (i.e. a linear development such as a ditch or a permanent sediment pond) becomes the primary best practice.

Onsite visits with proponent staff has proved to be effective for completing the more detailed erosion and sediment control planning for specific activities such as road construction and preliminary development of the mine pit area. Among other information gathered, such onsite visits enable a site-specific assessment of local soil characteristics and the potential presence of surface or near surface seepage. As an example, for one of the surface coal mines worked on, onsite visits with proponent staff were used to generate more detailed, activity specific erosion and sediment control plans. In this instance, meeting onsite with proponent staff to plan mitigation measures for specific erosion and sediment control issues helped obtain in a timely fashion an effluent permit covering a proposed change to the original mine

development plan. Of importance to note with this example is that the most effective approach for surface erosion protection and sediment control planning would be to support the detailed site-specific planning with a higher level process focused on identifying higher risk areas and avoiding these areas if possible.

DEVELOPING EFFECTIVE BEST PRACTICES FOR SURFACE EROSION PROTECTION AND SEDIMENT CONTROL

Context for Erosion Protection and Sediment Control During Development of a Surface Mine

Surface mining potentially involves significant disturbance of the landscape including but not limited to the disruption of natural drainage patterns, the exposure of soils to erosion, and the entrainment and transport of eroded sediments to valuable aquatic environments downstream of the mine footprint. Rates of erosion and sedimentation can rapidly increase with increasing levels of land disturbance. Given the scale of disturbance, it is not always feasible to completely avoid disturbance of areas characterized by erodible soils and potential seepages. Controlling sediment thus becomes critically important and typically involves construction of a water management system consisting of upslope diversion ditches, onsite collection ditches, and a large sediment pond or number of ponds at a single location throughout the mine site; typically at the point of lowest elevation. The water management system diverts non-contact drainage around the mine site. This minimizes the amount of surface runoff thereby limiting the potential for rill and gully development on disturbed landscapes and saturation of the soil at specific areas, which can produce deep seated slope failures in some instances. The water management system also collects and impounds contact water onsite so that a design fraction of suspended sediments are settled out of suspension prior to discharge into a natural drainage system.

Whereas the water management system focuses on the diversion of drainage around disturbed areas and the collection and treatment of sediment-laden water, best practices for erosion protection and sediment control provided in this section are intended to minimize erosion and control sediment as near to the source as possible. In this way, these practices for erosion protection and sediment control augment the water management system by aiming to reduce the sediment load (in the form of sediment-laden runoff generated as a result of land disturbance) handled by the water management system. Even more importance is placed on this aspect of erosion protection and sediment control when preliminary mine development activities are scheduled in conjunction with construction of the water management system. Assuming disturbance of or runoff over higher risk areas is avoided or minimized to the greatest extent possible, this approach is consistent with relevant literature that identify erosion control as a ‘first line of defense’ based on an underlying rationale that less erosion will equate to less load placed on downslope sediment controls (Bigatel et al. 1998).

Defining Erosion and Sediment Control

Understanding the difference between erosion control and sediment control is important when considering effective approaches for minimizing erosion and sedimentation resulting from land disturbance. Erosion control practices protect the soil surface and prevent the detachment of soil particles by wind or water.

Effective erosion control minimizes the need for sediment controls. One of the most effective erosion controls is a self-sustaining vegetative cover. Vegetation provides protection from splash erosion, greatly reduces the potential for overland flow, and helps to maintain the infiltration capacity of the soil thereby minimizing the amount of surface runoff generated.

Sediment control practices use gravity to capture soil particles after having been transported away from their source by wind or water. Sediment controls typically function to settle soil particles out of the water by impounding surface runoff and reducing the velocity of flow. In general, minimizing erosion is much more cost effective than implementing sediment control, although it is not always practical.

Understanding Erosion Processes

Landscapes disturbed from surface mining will be subject to different erosion processes. Bigatel et al. (1998) describes five main erosion processes, which are summarized in Table 1. The primary erosion agent is water. Each process is caused by water impacting the landscape – either in the form of raindrops falling from the sky or flow on the land surface.

Table 1. Summary of five main erosion processes (Bigatel et al. 1998)

Erosion process	Defining characteristics and general approach for mitigation
Splash	• caused by raindrops impacting the ground and dislodging soil particles • severity of erosion increases with the size and velocity of raindrops • removing vegetation exposes the landscape to splash erosion • best practices for mitigation include minimizing vegetation removal, applying mulches or installing erosion control blankets to reduce the kinetic energy of raindrops, and establishing a protective layer of vegetation as soon as possible after disturbance
Sheet	• occurs when rainfall forms a thin layer of flowing water on the land and transports soil particles dislodged by splash erosion • best practices for mitigation are similar to splash erosion, but can also include installing sediment fences to disrupt surface water flow paths
Rill	• occurs when runoff begins to concentrate in small channels and the shearing force from water begins to erode soil particles • evidence of rill erosion is indicated by the presence of small, uniform, parallel channels flowing downslope • controlling surface runoff is important for minimizing the potential for rill erosion; minimize slope lengths by disrupting surface flow paths also inhibits the potential formation of rills
Gully	• represents a progression from rill erosion when the smaller channels intersect to form larger channels; in turn the erosive power of the flowing water increases with increasing volume • a gully will continue to erode and grow in size until a more erosion resistant layer is reached • whereas rills are more easily removed using heavy equipment to re-grade a site, gully erosion leaves large defined channels that can be more difficult to stabilize
Channel	• occurs in natural streams and in road, diversion, and collection ditches • is a natural process in stream channels that is exacerbated when the hydrology or channel geometry is impacted by development • improperly designed stream crossings can result in localized channel erosion • armouring ditches with rock and installing structures to slow water velocities are common practices for mitigating channel erosion in ditches.

There exists a progression from sheet erosion to rill erosion and then to gully erosion. For a disturbed landscape where erosion protection and sediment control practices are not implemented, factors such as topography, climate, and soil characteristics will determine the rate at which these processes progress. The presence of surface and near-surface seepage can exacerbate the erosion process. Integrating the results of overview soil assessments and surface / near surface hydrology assessments into the planning process helps maximize the effectiveness of surface erosion and sediment control best practices by

matching the appropriate practice to the erosion process or processes operating at the site and the existing site condition.

Approaches for Prescribing Erosion Protection and Sediment Control Best Practices

Sediment fences, sediment traps, erosion control blankets, hydro-seeding, and tracked contouring are but a few of the numerous practices available for erosion protection and sediment control. The number of different practices can be confusing. This is especially true when combinations of different practices can achieve the same objective. Our experiences have demonstrated an effective framework for prescribing best practices for specific sites and activities first considers runoff control as a critical element of erosion control that must be addressed before anything else. This is followed by protection of disturbed surfaces from splash erosion. Sediment controls are addressed last.

For any landscape disturbance, prescribing runoff control best practices first ensures that existing sediment source problems are not exacerbated and new problems do not develop as a result of poorly managed drainage. Once runoff has been properly managed, additional erosion control best practices are implemented to minimize erosion at the source. It is important to recognize that even for a small area, it is impossible to completely prevent erosion once the landscape is disturbed. This is especially true with surface mining given the scale of development both spatially and temporally. Thus, sediment control best practices are also typically implemented to mitigate for sedimentation resulting from increased rates of erosion.

Understanding what erosion process or processes are functioning is important for prescribing the appropriate sediment control practice. Because there is a progression from sheet to rill to gully erosion (and in some cases this extends to channel erosion), the type of sediment control practice required is often dictated by what point in this progression sediment is to be controlled. A prime example is the installation of a sediment fence. While sediment fences work well for minimizing sheet erosion and slowing the velocity of sheet flow so that entrained sediments can settle out of suspension, they are not intended for controlling sedimentation resulting from rill, gully, and channel erosion in ditches. In contrast, a ditch system and sediment pond can provide sediment control for all phases of the erosion process, including erosion from sheet flow. An approach to erosion and sediment control advocating controlling sediment as close to the source as possible would therefore utilize variety of best practices that could include measures to disrupt surface flow patterns on disturbed landscapes and settle suspended sediments in smaller sediment traps closer to the source. These measures could augment the ditching system and larger sediment ponds designed to manage sediment generated over the entire mine site from all forms of erosion.

IMPLEMENTATION

The best practices provided in an erosion protection and sediment control plan are only effective if implemented according to the plan. In comparison to the operations phase, the development phase of a mine is a much shorter time period. Yet, this phase is the most critical for ensuring the appropriate measures are in place to manage erosion protection and sediment control over the life of the mine. There

are two sides to implementation. On the one side, professionals working in the field of erosion and sediment control must produce plans that match site conditions with best practices that will be effective for meeting realistic objectives. On the other side, commitment from the proponent for implementation of the plan comes in the form of providing onsite supervision for specific plan components and making sure all onsite mine staff, from supervisors to contractors are aware of, and committed to, implementing the erosion protection and sediment control measures prescribed for specific phases of development. Specifically, effective implementation requires the responsibility for ensuring proper implementation of these tasks is given to one person who works onsite and oversees all phases of mine development. Ideally, this person would be experienced in erosion and sediment control and would be responsible for monitoring the implementation of the plan on a continual basis.

Effective implementation may also require a plan be adapted to changing circumstances. Continuous monitoring of the implementation of the surface erosion protection and sediment control plan would help facilitate this by identifying when alternative best practices will achieve the same environmental objectives. For one mine currently being developed that we have worked on, having a professional experienced in surface erosion protection and sediment control onsite during specific construction activities has also proven effective for implementing the original plan and adapting the plan to changing circumstances.

EXAMPLES OF BEST PRACTICES FOR SURACE EROSION PROTECTION AND SEDIMENT CONTROL

Activities that comprise the development phase of surface mines can be grouped accordingly: linear developments including temporary and permanent roads, and power lines; mine infrastructure and pit area development; and construction of the water management system including diversion and collector ditches and main sediment ponds. Described in the sub-sections below are erosion protection and sediment control best practices relevant to each activity group. The overview is based on *Environmental Dynamics'* experience working with several proponents mining in northeast BC and review of select literature.

Linear Development – Erosion Control for Road Approaches and Stream Crossings

Establishing permanent self-sustaining vegetation is the most effective means for minimizing erosion from cut slopes and fill slopes and disturbed areas adjacent to road ditches. Seeding and re-seeding with a locally adapted seed mixture is required to establish vegetation. It should be noted that applying fertilizer might be required to establish vegetation that is effective for erosion control. Large, exposed cut slopes and fill slopes do have the potential to form rills after only one or two significant storm events. For this situation, in addition to seeding, *Environmental Dynamics* has had success minimizing rill erosion by installing straw wattles spaced evenly across the slope on the contour. The straw wattles reduce the length of the slope and minimize the onset of sheet and rill erosion processes, which enables permanent vegetation to establish. Straw mulch and tackifier applied over top of the straw wattles has proven effective for protection from splash erosion.

Local channel erosion can result from a poorly designed and managed stream crossing. For permanent roads, culverts or bridges should be properly sized and riprap used to protect areas exposed to flowing water. A de-watered work area is critical for minimizing erosion and sedimentation during installation of culverts for locations determined to be high risk. 3-inch water pumps for smaller streams (<1.4 m wide) and diversion ditches for larger streams – depending on stream discharge at the time of construction – are most effective for isolating proposed culvert installation work areas. Risk in this context is subjective and is dependent on fish-bearing status and or the distance to fish-bearing reaches. Retention of a professional to determine the appropriate level of best practices required is recommended.

Significant local channel erosion can also occur in ditches constructed in steeper terrain or in more erodible soils. Standard resource road construction practice aims to minimize erosion by installing cross drain culverts to shorten the length of the ditch and maintain natural drainage patterns. In addition to this measure, armouring specific segments of ditch with rock is an effective means of minimizing channel erosion. Ditch armouring was recommended for certain segments of the main haul road leading to a mine in northeast BC. In this example, the ditch armour prescription was in response to an onsite survey that noted areas of highly erodible soils in close proximity to seepage areas where larger cuts were also required for road construction. This particular road segment was located in steeper terrain along a slope with direct connectivity to a stream channel.

Linear Development - Managing Runoff and Sedimentation From Roads

All linear developments disrupt hillslope hydrology by capturing near-surface water in conduits such as ditches that can quickly deliver runoff to a stream channel. In addition, linear developments expose soil on cut and fill slopes to erosion and reduce the rate of infiltration, which in turn generates greater volumes of surface runoff. Roads crossing streams outside of the mine footprint will convey sediment-laden water directly to downstream aquatic systems and a poorly designed crossing will cause excessive channel erosion.

Runoff control for roads requires construction of ditches to manage drainage. Best practices for managing drainage for roads on or adjacent to surface mines are consistent with methods for constructing any natural resource access road. One effective best practice is to divert ditch drainage to stable, vegetated areas thereby preventing direct input into a stream channel or collection ditch. This approach uses the vegetation as a filter to remove sediment particles in suspension. Structures designed to slow runoff velocities and settle suspended sediments are also effective for removing sediment from runoff contained in ditches that cannot be diverted to stable, vegetated areas. Two types of structures have proven effective. Fifield (1997) provides detailed design specifications for a sediment trap consisting of a small basin that is installed in a ditch or as part of a drainage management system. McBride (2002) describes a similar structure that uses gravel and sand bags to form the ditch block and was highly successful for settling sediment in ditches at Kemess Mine. Both techniques emphasize that complete removal of sediment is not possible, but that the structures in general are effective for reducing total sediment loads. McBride (2002) highlights the importance of innovation by recommending a cascading series of gravel / sandbag check dams to increase effectiveness of sediment removal. Sediment traps as

described by Fifield (1997) have been the typical practice we have prescribed for the projects we have worked on.

Erosion and Sediment Control for Mine Infrastructure and Pit Area Development

Widespread removal of treed vegetation and grubbing of ground cover is required to prepare the pit area for development and the soil stockpile and waste rock areas. A number of practices are recommended to provide erosion protection and sediment control. Much of the treed vegetation present on the sites of recently developed surface coal mines in northeast BC consisted of non-merchantable young pine forests. For one mine development worked on, a tracked mulch machine that removes the trees and turns the wood into mulch was used. The wood chip mulch was immediately returned to the ground. The mulch provided effective protection from splash and sheet erosion for areas scheduled for development in subsequent years.

Typical grubbing practice involves moving grubbed material to large discrete piles or wind-rows. The grubbing of stumps and ground shrubs into wind-rows of material placed along the contour has proven an effective temporary runoff and sediment control measure of particular importance when initial grubbing occurs concurrently with construction of the water management system. Temporary ditching and construction of small sediment traps is also effective for managing runoff and sediment in this instance. Small, temporary sediment traps installed close to the area grubbed can help remove a component of the suspended sediment. The size of the traps and their temporary nature does not require an engineered design. The next progression from isolated, smaller, temporary sediment basins is to construct a series of slightly larger ponds that decant from the surface of the upstream pond to a downstream pond. McBride (2002) refers to this design as a series of 'polishing ponds' and reported on their success for helping to meet water quality objectives for the Kemess Mine South Project. A series of ponds enables longer retention times for the settling of suspended sediments.
To date, flocculants have not been used on the projects we have worked on to increase the effectiveness of temporary sediment traps / ponds and the permanent ponds constructed as part of the water management system. It is proposed that environmentally sound flocculants could be used for increasing the effectiveness of temporary and permanent sediment ponds constructed to manage sediment generated from grubbing and site grading.

Erosion Protection and Sediment Control for Soil Stockpiles

For sediment control and runoff management, containment berms constructed using existing material and placed around mine infrastructure (work areas, processing areas, stockpiles and waste areas) ensure sediment-laden runoff is contained within the site and or directed down slope to a sediment control structure. Establishing vegetation on stockpiled soils is the primary objective for erosion control. Erosion control practices are nearly identical to those for exposed cut-slope areas. For soil stockpiles, more emphasis is placed on incorporating benches into the final grade of the stockpile to shorten the slope length. 'Tracking' with machinery up and down the slope is effective for minimizing sheet erosion and creating microsites that enhance seed germination.

Construction of Water Management System

Construction of the water management system requires development of temporary trails to access collector and diversion ditch segments and the main sediment pond(s) area. Erosion and sediment control issues that arise are concerned with deactivation of the access trails, construction sequencing, and minimizing sedimentation resulting from stream diversions. Standard road deactivation practices provide a means applicable for trail deactivation. Such practices include re-establishing natural drainage patterns, removing any temporary crossing structures installed for access, pulling back fill slopes, using heavy equipment to harrow compacted soils, and re-vegetating exposed mineral soils. For the mining projects worked on northeast BC, practices prescribed have included managing surface runoff so that it is directed toward stable, vegetated areas and re-vegetating trails by applying appropriate erosion control seed mixture. Material excavated to construct diversion and collector ditches is often cast to the side rather than hauled away. Casting material to the downslope side of the ditch is considered a best practice for minimizing the amount of additional sediment input into the water management system. Establishing vegetation on soil cast to the side is the primary means of erosion control.

Engineered design specifications are required to construct the rock armoured collector and diversion ditches that form the water management system. Natural streams are routed into the diversion ditches, which then carry the non-contact water around the mine footprint. While the rock armour protects against channel erosion over the long term, the diversion of a stream into a newly constructed ditch can produce a significant sediment pulse. The risk associated with the pulse depends on the magnitude and duration of the pulse and the distance to fish-bearing reaches. For segments of ditch considered higher risk, using structures to impound flow at the downstream end of ditch segments and a water pump to remove sediment-laden water (i.e. pump the sediment-laden water to a stable vegetated area) is an effective means for reducing the magnitude and duration of the sediment pulse. A similar structure to a rock check dam or a gravel / sandbag dam placed in the ditch is used to block the flow of water. Once the risk to downstream aquatic values has been reduced to an acceptable level, the structure used to block flow is removed.

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