



ENVIRONMENTAL DYNAMICS INC.
Natural Resource Consultants

**RUNOFF, EROSION AND
SEDIMENT CONTROL BEST
MANAGEMENT PRACTICES
FOR YUKON PLACER MINING
OPERATIONS**

Prepared for:

**Fisheries and Oceans Canada
Habitat Management Sector**
100 - 419 Range Road
Whitehorse, YT
V1A 3V1

Prepared by:

EDI ENVIRONMENTAL DYNAMICS INC.
Suite 206-4133 4th Avenue
Whitehorse, Yukon
Y1A 1H8

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PREFACE

This report has been prepared for Fisheries and Oceans Canada (FOC) to assist in the development of Best Management Practices (BMPs) for effective runoff, erosion and sediment control procedures within the Yukon placer mining industry. The objectives of this report are to examine, discuss and document runoff, erosion and sediment control practices as they relate to the physical components of Yukon placer operations.

DISCLAIMER - FIGURES

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PROJECT TEAM

Authored by:

Adam Compton, B.Sc., B.I.T.

Direction and editing:

Patrick Tobler, R.P.Bio.
Robert J. Redden, R.P.Bio, CPESC

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1.0 INTRODUCTION

Soil erosion is a naturally occurring process that plays many important roles in the development of drainage basins, stream channel processes and aquatic habitats. Erosion rates are easily accelerated when land is disturbed by natural events and human activities. Increased rates of soil erosion can impact physical and biological equilibriums that have established over long periods of time within watersheds. Once significant impacts caused by excessive soil erosion have occurred, it can take many years before natural conditions are reestablished. These impacts can have significant consequences to the aquatic environment and the fisheries resource, especially when cumulative impacts over broad spatial and temporal scales are considered. The importance of minimizing and preventing impacts to aquatic environments during the extraction or development of natural resources cannot be overstated due to the social, economic and intrinsic values of aquatic resources.

Large areas of soil disturbance are often associated with the mining industry as mining involves the direct extraction of ores and minerals from the earth. Placer mining is no exception. Significant quantities of alluvial materials are excavated across large surface areas, often located adjacent to or within riparian areas. The need to implement effective runoff, erosion and sediment control practices throughout all operations of placer mining, from grass roots exploration to final site reclamation, is imperative to the protection of aquatic resources from unnecessary degradation.

2.0 EROSION, SEDIMENT AND SEDIMENTATION

2.1 Definitions

Soil erosion is defined as the process through which soil particles become detached from a surface by ice, wind or water. Once eroded, soil particles are defined as **sediment** when they become suspended in water or wind. **Sedimentation** occurs when sediment falls out of suspension and is concurrently deposited onto a surface.

The majority of soil erosion associated with ice is through glacial processes; but some can occur in streams when ice flows are present. Wind erosion can be a significant factor contributing to soil loss in areas with unvegetated, or poorly vegetated soils that are exposed to prolonged high wind events and is a significant concern with respect to topsoil loss in the agriculture industry. Although soils that are exposed during placer mining activities can be susceptible to wind erosion, it is of much less concern than soil erosion caused by water. As water is a necessary component of placer mining operations, and as placer mining typically occurs within, or adjacent to, natural water bodies, the concern for negative impacts created by hydraulic erosion and the potential for associated sedimentation is high with respect to aquatic communities and their habitats. Due to the force of gravity, soils eroded and transported down slopes by water, often end up in water bodies when not obstructed in some way.

As placer is, by definition an alluvial deposit, it is typically adjacent to or beneath existing water bodies along or near valley and gully bottoms. Placer mining typically involves the removal of large quantities of topsoil and vegetation, termed overburden, to access the paydirt below. Placer mining also requires the use of water in the sluicing process, which serves to separate and sort the soil particles in the paydirt. These activities typically involve the use of heavy machinery. As such, the need for controlling and minimizing the introduction of sediment into the natural water bodies from both the sluicing process and from exposed soils from adjacent areas is imperative during placer mining operations.

2.2 Types of Erosion

In general, there are five types of hydraulic soil erosion, each of which is described below (and illustrated in Figure 1).

- **Splash (raindrop) erosion** is the detachment of soil particles resulting from the impact of raindrops falling directly onto a soil surface.
- **Sheet erosion** is defined as the uniform removal of thin layers of soil from unchannelized water flowing across a sloped surface.
- **Rill erosion** occurs when soil is removed by water flowing through short-lived, discontinuous, shallow channels or streamlets that have formed across a sloped soil surface.
- **Gully erosion** is an advanced stage of rill erosion that occurs when rills become enlarged and form gullies, which are longer-lived, deeper channels.
- **Stream channel erosion** includes the removal of soil along channel banks and riparian areas, as well as the scouring of sediment from the channel bed.

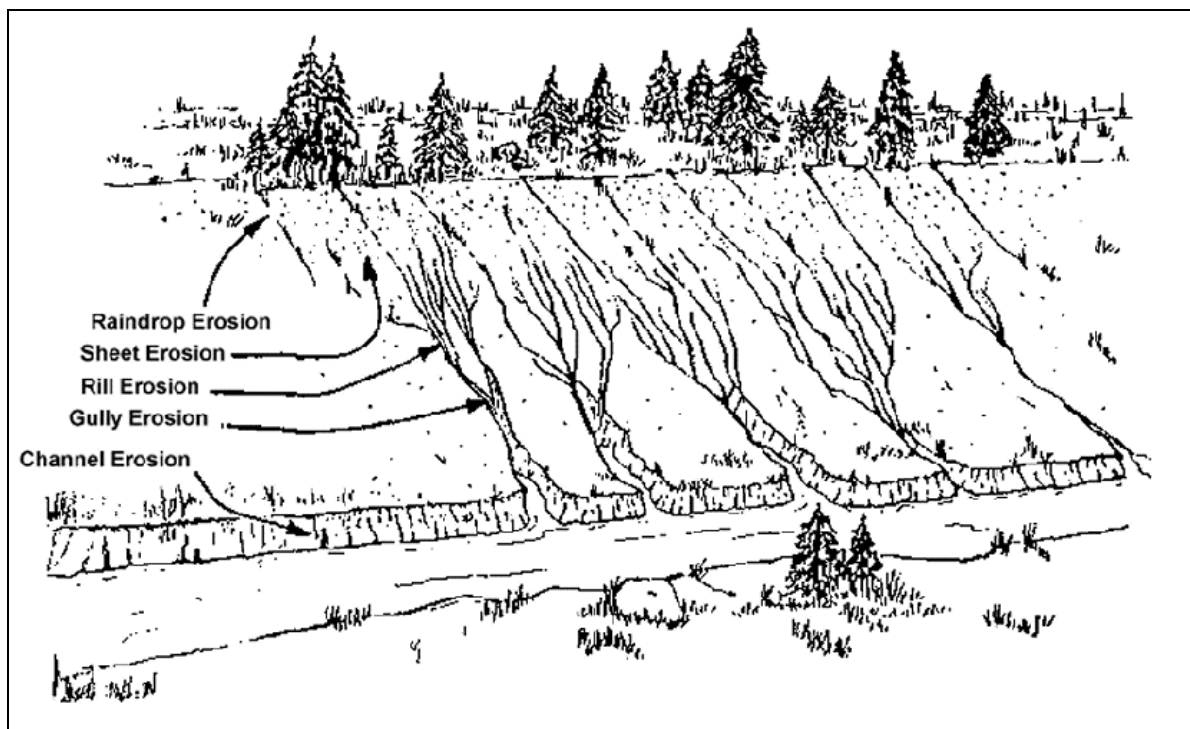


Figure 1. Types of hydraulic soil erosion (Colorado Department of Highways. 1978).

The precise definition of sheet erosion rarely occurs, as it requires a uniform, flat surface that water can pass over without forming rills. The definition of sheet erosion is useful to describe the stage of erosion that occurs immediately after splash erosion and prior to rill erosion. Water associated with snow melt typically starts at the sheet erosion stage of the erosion process. Rill erosion is a more common form of soil erosion. Very small rills typically form immediately downhill from the top of a slope where only splash and sheet erosion occur. Once formed, sediment-laden runoff has become somewhat channelized and the water's velocity and erosivity potentials have increased. Most of the rainfall-induced erosion occurs through the process of rill erosion. As rills grow in size, depth and continuity, they may cause the formation of intermittent channels, or gullies. Gullies can also form without the prior development of rills when large volumes of runoff are discharged onto steep slopes with erodible soils. Gully erosion is often responsible for mass wasting events (e.g. land slides and debris torrents).

Stream channel erosion should be considered separate from direct rainfall associated processes described above, as the variables that govern the processes are quite different. Fluvial geomorphology processes are numerous and not only determine whether sediment is eroded or deposited within an area, they determine the width, depth, shape and longitudinal profile of a stream.

From a runoff, erosion and sediment control perspective, the order in which these five types of soil erosion caused by water are listed corresponds to the difficulty of controlling these processes. Splash erosion is the easiest and most effective erosion process to manage, while channel erosion is the most difficult and least effective.

KEY CONCEPTS
<ul style="list-style-type: none">• From a runoff, erosion and sediment control perspective the order in which these five types of erosion are listed corresponds to the difficulty in which they are controlled.• Splash erosion is the easiest to control effectively and channel erosion is the most difficult.

3.0 VARIABLES THAT INFLUENCE RUNOFF, EROSION AND SEDIMENTATION

There are several interrelated and interacting natural factors that influence soil loss within any given geographical area. The most important of these include precipitation/climate, soil type, topography and vegetation.

3.1 Precipitation/Climate

Climate is one of the most important factors that influence the potential for soil erosion in an area. Over a broader timescale, climate plays a role in the development of soil and vegetation, while climate immediately determines the quantity of precipitation. The climatic conditions determine how much, how often, and what type of precipitation occurs over a given area. While the other factors mentioned above are also very important, climate can be viewed as the first step in determining the potential for soil erosion as it quantifies the amount and intensity of the erosive agent (water, wind or ice). Higher rates of precipitation and snowmelt will increase the potential for soil erosion to occur no matter what the other conditions may be.

All of Canada is classified into several ecozones that describe the spatial extent of several general landscape and climate characteristics. The Yukon Territory contains five different ecozones: the Pacific Maritime, the Boreal Cordillera, the Taiga Cordillera, the Taiga Plains and the Southern Arctic. Each ecozone is further divided into ecoregions based on more specific environmental characteristics. The description and location of Canada's ecozones and ecoregions are available online at Environment Canada's website (http://www.ec.gc.ca/soer-ree/English/Framework/NarDesc/canada_e.cfm).

Most of Yukon lies within the Boreal Cordillera and Taiga Cordillera ecozones. Eleven of the twelve ecoregions of the Boreal Cordillera Ecozone are present within the Yukon Territory. The Boreal Cordillera Ecozone is characterized by long, cold winters and short, warm summers with mean annual temperatures ranging from 1°C to 5.5°C (Environment Canada Website 2003). Precipitation ranges from approximately 300 mm at lower elevations to up to 1500 mm at higher elevations (Environment Canada Website 2003).

The Taiga Cordillera Ecozone contains seven ecoregions, all of which are present within the Yukon Territory. This ecozone is also characterized by long cold winters and short, warm summers. Average annual temperatures range from -10°C in the north to -4.5°C in the south and precipitation ranges from 300 to 700 mm (Environment Canada Website 2003).

The long, cold winters that occur in Yukon are associated with the presence of permanently frozen ground, known as permafrost, in many areas. The presence of permafrost is an important factor with respect to soil erodibility, and will be discussed further in the subsequent section.

The erosive power of rain can be a very significant contributor to soil erosion on hillslopes (splash erosion). Raindrops possess a considerable amount of kinetic energy, which is derived from their mass and velocity (momentum). Large quantities of soil can be removed as a result of this process. It has been estimated that 37 tonnes/hectare (100 tons/acre) can be splashed into the air during a heavy rainstorm on bare, flat soil (Ellison 1948). Dislodged particles can move more than 0.6 m vertically and 1.5 m laterally on a level surface (Gray and Sotir 1996). On a sloped surface, this splashing will cause a net movement of soil downhill, as dislodged particles are able to move further in the downhill direction. The ability of rain to cause soil erosion is attributed to the size of the raindrops and the rate of rainfall.

Another way in which splash erosion contributes to increased rates of erosion is the ability to decrease the soils permeability. Soil particles dislodged by rainfall can fill the interstitial spaces within the soil surface causing the surface to become less permeable, and in extreme cases, entirely impenetrable. A less permeable soil present on a sloped surface leads to increased runoff and the formation of rills as precipitation rates can easily exceed infiltration rates.

ACTION ITEM
<ul style="list-style-type: none">• Determine which Ecozone and or Ecoregion the development is located in, to get a general understanding of which climatic factors will affect erosion potential.

3.2 Soil Characteristics

Soil characteristics that determine the erodibility of the soil as well as the soils permeability and water holding capacity are extremely important factors in determining the potential for soil erosion.

Soil texture is the primary factor that determines soil erosivity. Fine textured soils are smaller and more easily transported by water, than coarse textured soils. Soil cohesion, however, is a factor that determines how easily the soil is detached from a surface. Cohesive soils with fine textures, such as clays, are often very stable and do not erode easily. Fine textured soils that have low cohesion are the most erodible. Coarse textured soils are only erodible at high water velocities. Uncompacted sandy soils are often the most erodible as the texture is fine, but cohesion is relatively low.

Once eroded from a surface, sediment particle size is an important factor in terms of how long it will remain in suspension. The coarser the sediment texture, the more easily it will fall out of suspension and be deposited. Once in suspension, silts and clays can remain in suspension for extremely long periods of time, as their small particle size requires considerable time in very slow moving or still water to fall out of suspension.

Figure 2 describes the relationship between particle size and water velocity. This relationship is important in understanding the water velocities required to erode, transport and deposit various particle sizes.

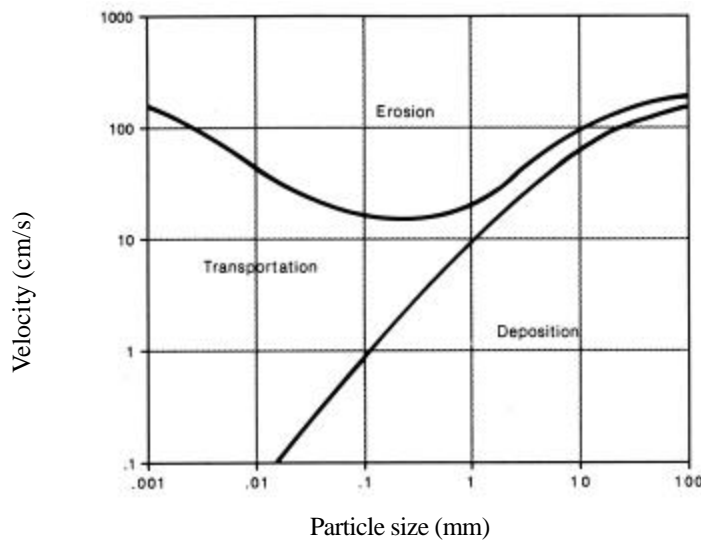


Figure 2. Diagram of the relationship between particle size and water velocity (adapted from Hjulstrom 1935).

Soils can have the ability to absorb large quantities of precipitation. Water immediately absorbed by the soil means that little or no water will move down slope as surface runoff. Soil permeability is the measure of a soils ability to absorb water. A soil’s permeability is directly proportional to its porosity. Soils that are not compacted and have spaces or pores located throughout the soil matrix allow for the movement of water. The amount of water that a unit of soil can contain is known as its water holding capacity. Soils that are saturated have reached their water holding capacity. Once this occurs, or once the infiltration rate is exceeded by the rate of precipitation, any additional input of water to the soil

surface will pool on flat surfaces or runoff on sloped surfaces. The top layer of soil is the most important layer with respect to the soils ability to prevent runoff. If water cannot penetrate the soil surface, the soils water holding capacity, porosity and permeability beneath the surface become irrelevant with respect to the prevention of runoff.

Permafrost, which is present sporadically throughout most of Yukon and continuously throughout the northern parts of the territory, is an important soil characteristic that has many implications in terms of soil erosion. Permafrost is a zone of permanently frozen ground that can extend down several meters and is usually covered by a relatively thin layer of material (15 cm to 5 m), known as the active layer, that freezes and thaws on a seasonal basis. Frozen soils are more stable and less susceptible to erosion than unfrozen soils. Frozen water present within the soil binds the soil particles into a solid mass. As soil pores are filled with ice, frozen soils are much less permeable and water tends to only flow along fractures present within the soil. The reduced permeability can lead to increased runoff and slope failure as the frozen soil has a very limited (liquid) water holding capacity.

Ice rich soils also known as black muck are made up of finer grained materials and become very unstable when melting occurs. When melting of this material occurs along a slope, mass wasting often results. Melting of frozen soils can occur when the soil is exposed for sufficient lengths of time as a result of some kind of disturbance. The active layer acts as an insulator and its removal can cause accelerated rates of permafrost melting. It is very important to minimize disturbance to frozen soils whenever possible.

ACTION ITEMS
<ul style="list-style-type: none">• Determine soil types present and their associated erodibility.• Identify high hazard areas (steep slopes, permafrost etc.).

3.3 Topography

The length and angle of a slope have a major bearing on the potential for the occurrence of soil erosion. The longer and steeper the slope, the more susceptible to erosion it will be. Longer slopes promote higher runoff velocities by prolonging the acceleration of water due to the force of gravity. As water accelerates, it becomes more erosive. The distance traveled by eroded sediment increases proportionally with slope gradient. Without some sort of a break in the slope, surface erosion develops into rill erosion, which can then progress into gully erosion and the formation of channels.

ACTION ITEM
<ul style="list-style-type: none">• Identify steep and long slopes that may be susceptible to erosion.

3.4 Vegetation

Vegetation provides several extremely important functions in the prevention of soil erosion. Vegetation provides a protective layer over the soil surface that absorbs the impact of precipitation. This function, known as interception, can significantly reduce splash erosion. Interception can also reduce the amount of water that reaches the soil surface due to absorption and evaporative losses. However, water that has been intercepted and subsequently falls from a mature forest canopy can be more erosive than the original raindrops. This is due to the increased size of water droplets that can occur during reduced falling velocities; a water droplet's maximum potential size is inversely proportional to its velocity. Low-lying vegetative cover that intercepts water falling from a higher canopy above is, therefore, very important in the interception process. As such, a well-established, dense layer of vegetation present immediately above the soil surface can be very effective at preventing the erosive effects of direct rainfall and water falling from the forest canopy.

The presence of vegetation on slopes can provide a great deal of stability to the slope, both on the surface and deep within the soil matrix. The removal of vegetation from a slope can lead to increased rates of erosion and/or slope failure. Roots, which can extend to considerable depths within the soil can provide mechanical reinforcement of the slope, which increases its structural integrity and shear strength. Roots also adhere to soil particles preventing them from easily eroding.

Roots also play an important role in increasing soil permeability and its infiltration capacity. Roots provide avenues that water can follow along to penetrate the depths of the soil. Roots penetrate the soil, breaking it up and leaving behind pores that may not otherwise have been present. The increased porosity increases the soil's water holding capacity.

Vegetation along a sloped surface provides surface roughness that acts to slow the velocity of surface runoff. Slowing the water vastly reduces its erosivity. A dense vegetative cover can virtually stop erosion caused by runoff. Slowed runoff velocities also allow the water to make its way into the soil rather than continuing to flow along the soil surface, thus directly reducing runoff amounts.

Vegetation also consumes soil water through the process of evapotranspiration. This can be an important process where significant amounts of water are present in the soil. Saturated soils on slopes can often become unstable due to the increased weight and decreased soil cohesion provided by the excess water. When vegetation is present to effectively reduce the amount of water present in the soil, slope stability concerns are reduced.

The presence of vegetation also increases the incorporation of organic matter into the soil, resulting in better structural and water-holding qualities in the soil. Vegetation also provides suitable conditions for other biota to inhabit the area, which increases the potential amount of organic matter content within the soil. Increased faunal and biological activity, leads to better soil structure with respect to porosity and water holding capacity.

ACTION ITEM
<ul style="list-style-type: none">• Identify areas where vegetation should not be removed (where possible limit the area of clearing).• Where vegetation clearing is required, identify areas where the understory and organic layer can be left intact (where possible limit the area of grubbing).

4.0 THE IMPACTS OF EROSION AND SEDIMENTATION

Erosion and sedimentation occurring as a result of natural resource development and extraction activities have many important implications in terms of their environmental and financial impacts. Increased sediment causes changes in channel shape and form (morphology), stream substrates, the structure of fish habitats, and the structure and abundance of fish populations. Although the costs of implementing effective runoff, erosion and sediment control measures can be expensive, the costs of not meeting the requirements can be even more expensive in the long term.

4.1 Environmental Impacts

4.1.1 Physical Impacts

Increased rates of erosion and the resulting sedimentation can have many significant effects on the physical characteristics of a watercourse. A substantial introduction of sediment can result in changes to stream channel morphology as an adjustment of the balance between deposition (aggradation) and depletion (degradation) of stream substrates is forced to occur.

Increased sedimentation will lead to increased sediment deposition in lower gradient stream reaches. Over time, as portions of the stream channel continue to fill in with deposited sediments, the channel must widen in order to accommodate its normal seasonal flow levels. Bank scour and failure are common results of a widening stream channel. Bank failure often leads to a reduction in the channel's lateral stability, which, in combination with continued sedimentation could lead to further aggradation. Bank failure can be especially high when coupled with a loss of riparian vegetation, which would have otherwise provided substantial bank stability. In areas where severe aggradation has occurred, water may flow entirely beneath the aggraded material during low flow periods, which has serious implications to fish passage.

4.1.2 Biological Impacts

Physical stream channel characteristics dictate the types and abundance of aquatic habitats available for all aquatic organisms. Slight changes in stream channel characteristics can have significant biological implications. As described above, increasing the rates of erosion in a drainage basin results in direct changes to the physical characteristics of stream channels. Stream channels that have widened and aggraded have often lost a lot of habitat complexity.

Increased turbidity caused by an increase in suspended sediment concentrations can decrease primary production within streams. Primary producers such as algae and aquatic plants obtain energy from sunlight for photosynthesis. Increased turbidity can drastically reduce the amount of sunlight that penetrates the water, which may slow primary production.

Increased sediment levels can reduce the presence of some invertebrate species. The reduced numbers of invertebrates can be caused by increased invertebrate drift, as invertebrates move downstream to more favorable conditions, and lethal effects of high sediment levels. Increased invertebrate drift can be caused by a reduction of light, which is caused by increased turbidity, and by deposition of fine sediments over preferred coarser substrates. In a study conducted on placer-mined streams in Alaska, macroinvertebrate density and biomass decreased significantly in mined streams, as compared to unmined control streams (Wagener and LaPerriere 1985). Sediment deposited on stream bottoms,

affects the benthic or bottom dwelling invertebrate community by directly altering the benthic environment they inhabit.

Obviously, a reduction of invertebrate species will directly affect the fisheries resource in terms of decreased food availability. Several other well-documented effects of sedimentation on fishes may also occur.

Changes to the physical characteristics of the stream channel directly affect the type and abundance of fish habitat. The main concern with respect to loss of fish habitat has to do with spawning habitat as it is often the most sensitive to disturbance and has the greatest bearing on the survival of fish stocks. Reduced spawning potential directly affects the reproductive success of fish. Many sediment/fish related studies are focused on the impacts of sedimentation of the spawning gravels of salmonids. Salmonids typically spawn over gravel to cobble sized substrates, which are relatively clean (free of finer sized particles). Incubating eggs and newly emerged alevins, which are present within the spawning substrate, require a continual flow of water from which they obtain oxygen. If the flow of water is hindered by the accumulation of fine sediments overlying and within the interstitial spaces of the spawning substrate, survival is reduced accordingly. The accumulation of excessive amounts of sediment over spawning areas can cause the area to no longer be suitable for spawning.

Fish are adapted to tolerate fluctuating levels of water turbidity and sediment concentrations as they occur naturally to some extent in all streams. However, excessive levels of sediment beyond background levels for prolonged periods of time can be detrimental to the health of fish and if high enough can even directly cause mortality. Several studies have been conducted that document the effects that sediment has on fish. Some studies have also been conducted that document these effects occurring as a result of placer mining activities (for example see Liber 1992, Pentz and Kostaschuk 1997).

Sediment concentrations required to kill fish are quite high and do not often occur in pristine or disturbed streams. The concentrations required depend on the species tolerance at a given life stage and the length of exposure time; they typically vary from hundreds to thousands of $\text{mg}\cdot\text{L}^{-1}$ over a standard 96 hour exposure period (Birtwell 2000). Concentrations required to harm fish or alter their behavioral patterns are much less, ranging from tens to hundreds of $\text{mg}\cdot\text{L}^{-1}$ (Birtwell 2000).

In addition to the physical harm elevated sediment concentrations can have on fish, there are also several indirect effects that may occur. Examples of these effects include decreased feeding ability and predator avoidance. These responses are largely due to the reduced visibility that occurs as a result of increased turbidity levels. However, there is speculation that these effects may also be due to elevated levels of stress experienced by the fish in these higher levels of suspended sediment.

Fish also avoid areas of high turbidity or suspended sediment concentration as the abrasive nature of the often-angular shaped soil particles can harm fish gill filaments. Avoidance of areas with high concentrations of suspended sediment can effectively mean that the habitat is no longer suitable until levels go back down. If the sediment source is chronic, important habitat can be lost. This can have significant effects on fish species when occurring during crucial lifecycle stages such as migration and spawning.

4.2 Financial Impacts

Runoff, erosion and sediment control measure can add significant costs to placer mining operations. These measures must be implemented in order to prevent degradation of the natural environment and impacts to the financially significant fisheries resource. The financial costs are likely to be minimized if time is spent upfront doing extensive planning before mining operations begin. Not unlike the old adage, “an ounce of prevention is worth a pound of cure”, time and money invested in preventative measures will be less costly in the end. Erosion and runoff control measures are the cheapest to implement and are the most effective, often preventing unnecessary erosion and sedimentation from occurring.

Prevention of excessive site degradation throughout the duration of the mining activities will likely reduce some of the costs associated with reclamation. For example, leaving vegetative buffers around sensitive areas is much better than trying to reestablish vegetation, and minimizing erodible soil exposure times is more effective than dealing with the erosion that may otherwise result.

If improper placer mining practices with respect to limiting erosion and sedimentation result in significant environmental damage, the mining operation can incur penalties. Payment of fines and/or litigation costs can be very expensive to the operation. Avoiding fines and litigation by ensuring Best Management Practices (BMPs) are adhered to will likely be less costly in the end, and will offset negative public opinion of an operation and of placer mining in general.

Lowering of public trust and negative public opinion of placer operations can have significant implications for the future of placer mining. If public opinion of placer mining becomes negative due to the lack of effort by the industry to conduct proper practices, it will inevitably lead to more rigid regulation of the industry. Efforts made to follow guidelines and regulations will gain public support for the industry and will ensure the future of placer mining, while minimizing future policy changes that would likely increase operating costs.

5.0 RUNOFF, EROSION AND SEDIMENT CONTROL

5.1 Defining Runoff, Erosion and Sediment Control

To implement effective runoff, erosion and sediment control measures requires a comprehensive understanding of the processes occurring as well an understanding of the different control objectives of these measures.

Runoff Control:

The goal of runoff control is to mitigate for the erosive and sediment transport forces of water. This is done by limiting the concentration of water flow, decreasing water velocities and diverting runoff water to less erodible areas. Through the effective implementation of runoff control measures, the need for erosion and sedimentation control measures can be drastically reduced and in some case entirely avoided. By diminishing the strength of the erosive agent, and by redirecting it to less erosive areas, runoff control can be viewed as a primary preventative measure.

Erosion Control:

Erosion control measures are designed to prevent the detachment of soil particles by wind or water. The goal of erosion control measures is to avoid excessive erosion of soil from a site. Once runoff control measures have been implemented to reduce the effectiveness of the erosive agent, erosion control measures are employed to decrease the erosivity and, concurrently, increase soil stability. The retention of natural vegetation for erosion control can be viewed as a primary preventative measure.

Sediment Control:

Sediment control involves the implementation of measures that allow sediment to settle out of suspension so that the introduction of sediment-laden water to aquatic habitats is minimized. Slowing runoff velocities or impounding sediment-laden water for appropriate lengths of time can retain sediment. Both of these measures allow for the time required for the force of gravity to act on suspended fine sediments and bring them out of suspension. Sediment control does not involve the filtering of water, as there is no cost effective, feasible way in which to filter fine sediments from sediment-laden water.

KEY CONCEPTS
<ul style="list-style-type: none">• Retaining as much natural vegetation as possible is the most effective erosion control BMP.• Runoff and erosion control should be done first and sediment control last.

5.2 Steps for Effective Runoff, Sediment and Erosion Control

The objectives of preventing and minimizing erosion and sedimentation can be met by adhering to the following eleven principles, which can be applied to any type of development. Each of these principles is discussed with respect to specific aspects of Yukon placer mining.

ELEVEN PRINCIPLES TO MINIMIZE EROSION AND SEDIMENTATION

- 1. Fit the development to the terrain**
- 2. Time clearing and construction to minimize soil exposure**
- 3. Retain existing vegetation whenever feasible**
- 4. Vegetate & mulch exposed soils**
- 5. Divert runoff away from exposed soils**
- 6. Minimize slope length & steepness**
- 7. Keep runoff velocities low**
- 8. Prepare drainage ways & outlets to handle concentrated or increased runoff**
- 9. Trap sediment before it enters aquatic habitat**
- 10. Inspect & maintain control measures**
- 11. Installation of appropriate drainage crossing structures**

Fit the development to the terrain:

A well thought out development plan is paramount to minimizing potential environmental impacts. By taking into consideration the physical and biological characteristics of a site during the planning process, the best possible approach can be taken from the start. Rather than trying to mitigate for impacts caused by erosion and sedimentation after they occur, preventative measures should be implemented from the start and throughout the duration of the operation. Sensitive areas should be identified and avoided whenever possible. Things to consider with respect to runoff, erosion and sediment control include slope lengths, slope gradients, water drainage patterns and soil type to name a few.

Time clearing and construction to minimize soil exposure:

As placer mining in Yukon is restricted to only a few months of the year due to climatic variables, there is not a great deal of choice with respect to planning for the timing of operations. Reviewing ecoregion characteristics may assist in determining appropriate timing for clearing and construction activities. Clearing and heavy earthworks should be avoided during times of intense precipitation. Whenever possible, timing of clearing should be done so as to minimize the time in which soils will be exposed. Conducting periodic reclamation activities throughout the duration of the placer mining operation rather than performing all the reclamation activities when the mining operation is complete can also minimize soil exposure time.

Retain existing vegetation whenever feasible:

Removal of vegetation from all areas, especially within the riparian area, should be minimized whenever possible. Vegetation that must be removed from a site during clearing of overburden should be set aside and used to revegetate areas where mining activities are complete. Vegetation can be temporarily planted and stored in an area when a long period of time is anticipated before remediation of a site is due to commence. Vegetation removed during access road construction can be set aside and promptly replanted along sensitive areas of the road such as at stream crossings when road construction is complete. Note: much of the revegetation work identified above can be completed with an excavator.

Vegetate & mulch exposed soils:

It is important to vegetate and mulch exposed soils that are not within an active area. Grass seed is an inexpensive way to propagate the growth of vegetation on exposed soils. Various types of seed are available for many different applications and climatic zones. Mulching soils with straw, hay or other organic materials is another affective means of preventing erosion as it protects the soil surface from splash erosion. Vegetating and mulching should occur as soon as possible after soil exposure, especially along sloped surfaces.

Divert runoff away from exposed soils:

One of the most effective ways to prevent erosion of exposed soils is to limit the exposure of the soil to the erosive agent. Diverting runoff away from more erodible to less erodible areas is an important preventative measure. This principle is especially effective when runoff occurring on slopes can be diverted away from the exposed soils into soils that are adequately protected by a vegetative cover.

Minimize slope length & steepness:

All tailing piles and exposed side slopes should be contoured to reduce slope length and steepness. Slope steepness should be reduced to grades that are suitable to the erodibility of the soil material. For example, well-drained soils made up of coarser material and ice rich soils can be left at steeper grades than poorly drained materials. Recommended slope grades for various soil characteristics (Table 1) have been adapted from *Handbook of Reclamation Techniques in the Yukon* (Indian and Northern Affairs Canada 1999).

Table 1. Recommended slope grades for various soil characteristics.

Slope	Soil Characteristic	Recommended Procedures
Side Slope	Ice rich soil	Leave vertical. Undercut vegetative layer so it will fall and cover exposed slope.
	Less than 5% frost	Grade slope to less than 2:1. Round off top of slope.
	Coarse, well-drained soils	Grade slope to less than 2:1. Bench slope if over 15 m high.
	Fine, poorly-drained soils	Grade slope to less than 3:1.
Pile	Coarse, well-drained soils	Grade slope to less than 2:1. Round off top of pile.
	Fine, poorly-drained soils	Grade slope to less than 3:1. Round off top of pile.

Creating steps, or terraces, along the length of long (i.e., over 15 m high) slopes can effectively minimize the slope length. The placement of terraces, also known as benching, allows gradients of the slopes between the terraces to be left somewhat steeper as the erosivity of the entire slope has been decreased.

Keep runoff velocities low:

Slowing the velocity of runoff occurring over exposed soils is important in reducing the potential for erosion to occur. Reducing the velocity of runoff minimizes its erosive potential. Slowing runoff velocities can be achieved through several different methods, each of which either reduces the slope length or steepness, or increases the roughness at the soil surface. Terracing of slopes described above is one way in which runoff velocities are minimized. Other ways include:

- Revegetation of exposed soils.
- Placement of check dams along drainage ditches.
- Tracking slopes with heavy machinery.
- Spreading of organics on slopes (e.g. woody debris).

Prepare drainage ways & outlets to handle concentrated or increased runoff:

Ensuring that drainage ways and outlet areas will be able to withstand the amounts of flow they may receive is vital to ensuring that water will not flow beyond the limits of the drainage and into places where it may cause erosion and/or sedimentation. It is important that drainage channels and channel diversions not be constructed in perched locations as this will lead to the ease in which water may escape the channel. In addition, it is important that that the drainage ways are stable enough that they are not significantly eroded by increased flows. As such, they should be armored with appropriately sized substrates depending on the amount and velocity of water the drainage will receive. Drainage ways and outlet areas, therefore, should be of sufficient size and durable enough to handle all discharge levels that they may receive.

Proper drainage ways and outlets are very important issues with respect to placer mining as they often involve substantial changes to natural drainage patterns. Extensive channel and drainage diversions are often involved. The location and design of these drainages are important factors in minimizing the potential for excessive erosion and sedimentation.

Trap sediment before it enters aquatic habitat:

Placer mining methodology involves the implementation of this important step through the use of settling ponds. As the generation of sediment-laden water is inevitable when paydirt is washed in the sluicing process, it is important to trap the sediment before the water is reintroduced downstream. The design and maintenance of settling ponds is important so they function properly. Recommended design criteria are described in the *Placer Mining Design Handbook* (Nordin & D. Latoski 1989). Several settling ponds are often required to reduce the levels of sediment in the water to desired concentrations.

Recycling of sluice water has been found effective at reducing suspended solids without decreasing the effectiveness of the sluicing process (Johnson, J.H. Chapman, et al. 1987). In combination with proper settling pond design, sediment input into the receiving aquatic environment can be effectively reduced.

Inspect & maintain control measures:

Inspection and maintenance of control measures is essential to their long-term effectiveness. Sediment control structures require the highest amount of maintenance, as sediment that has settled out of suspension must be removed periodically throughout the lifespan of the control measure. If sediment control measures, such as silt fencing and settling ponds, are not cleaned out while still in use, the accumulation of sediment will cause the structure to not function properly and may even cause stored sediment to be washed into natural aquatic areas downstream. Failing sediment control structures can cause significant damage to the aquatic community when failure results in a large, abrupt discharge of fine sediments into the receiving environment.

Installation of appropriate drainage crossing structures:

Installation of appropriate crossing structures is very important in terms of minimizing erosion and sedimentation and ensuring fish passage on fish-bearing streams. All crossings have the potential to modify natural drainage patterns and affect erosion processes. Poorly designed and constructed crossing structures can lead to chronic erosion and impact fish passage. The size and type of crossing structures should be carefully chosen on the basis of bankfull channel width, stream gradient, fish species, habitat present, sensitivity of the site and length of time the crossing is expected to be used.

Crossing structure construction/removal may require site isolation, which can be achieved by pumping water around the site or some other means of temporarily diverting the water flow around the site. Site isolation allows the instream work to be conducted in isolated conditions so that sediment generation is minimized during construction/removal activities.

5.3 Runoff, Erosion and Sediment Control Methods

Proper site planning is the first and most important step to ensure that erosion, sedimentation and other forms of environmental degradation are minimized during placer mining operations. Once sufficient site planning with the goal of minimizing disturbance to sensitive areas has been conducted runoff, erosion and sediment control concerns should be addressed.

Controlling runoff can be viewed as a preventative measure that can negate the need of future erosion and sedimentation control measures. Runoff control measures are, therefore, much more efficient at preventing erosion and sedimentation and are often the cheapest to implement. Erosion control

measures are often more expensive to implement and usually require inspections and in some cases maintenance to ensure their continued effectiveness. As sediment control measures are the most expensive and least effective at keeping sediment out of aquatic environments, they should be left as the last approach considered during the development of an Erosion and Sediment Control Plan.

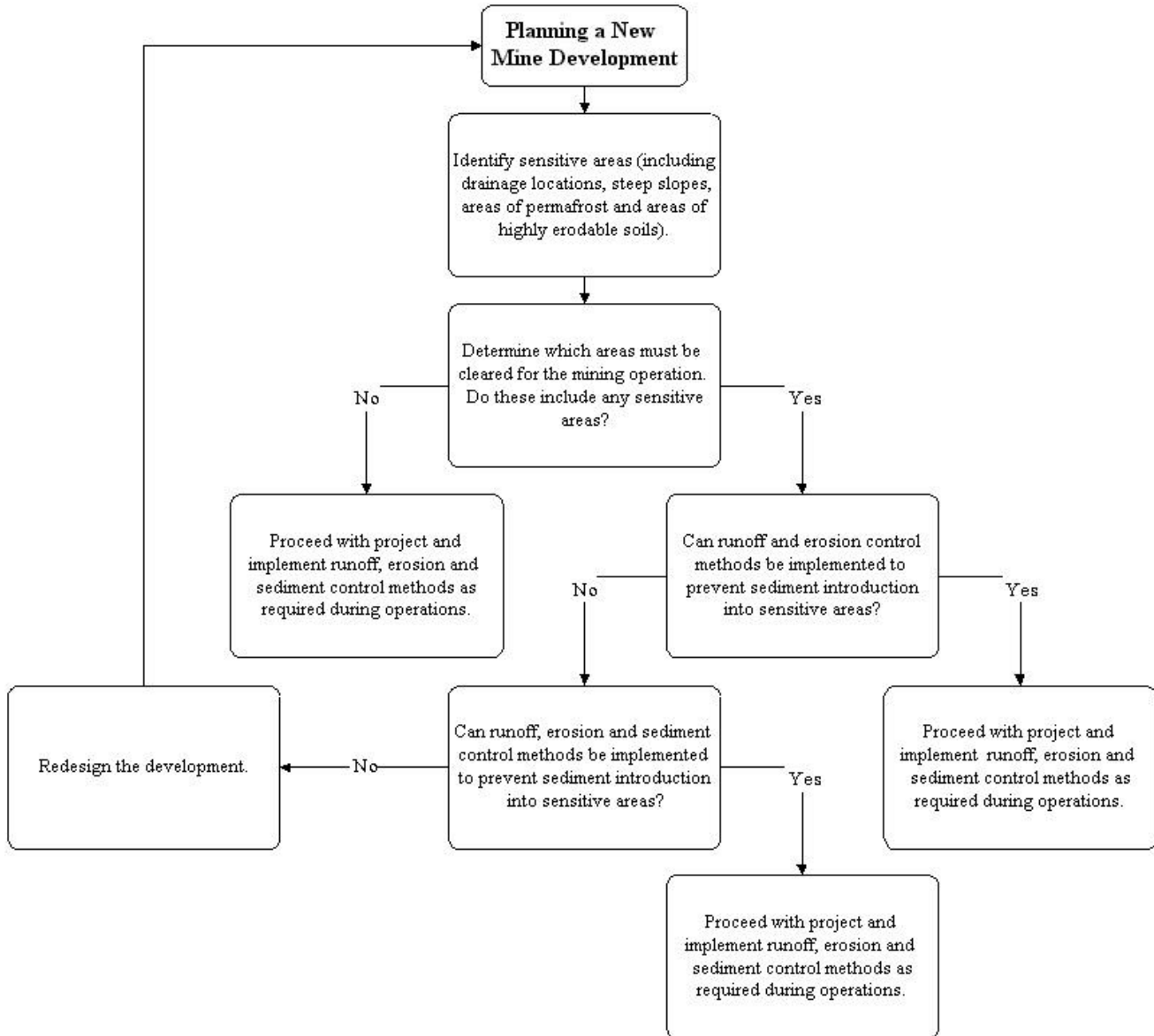


Figure 3. Planning a new mine development: runoff, erosion and sediment control flow chart.

The following sections describe the various runoff, erosion and sediment control measures that are applicable to the Yukon placer mining industry.

5.3.1 Runoff Control

Swales or Out-take Ditches

These structures are drainage ditches that are used to direct water away from streams and erodible areas and into natural vegetation or catch basins. These structures are typically used along roadways to convey accumulated ditch water into forested areas. This prevents road drainage problems by limiting the concentration of water in a ditch. Use of these structures can prevent road washouts caused by excessive ditch water. They are also very useful at limiting amounts of ditchwater entering streams at road crossings.

In addition to their use along roads, swales or take-out ditches can also be used in any area where exposed soils occur. In relation to placer mining this measure can be used in floodplain areas to divert concentrated runoff into well-vegetated areas away from the riparian area.

Natural topography should be considered when constructing these structures so that water is drained away from the roads or highly erodible sites. Stable natural depressions or vegetated areas should be used to receive the ditch water. These structures are associated with most well designed road networks, but are often overlooked for other applications and on small, privately owned and maintained dirt roads.

5.3.2 Erosion Control

Surface Roughening

Roughening of exposed soil surfaces is often overlooked and misunderstood. Exposed slopes are often left smoothly graded and compacted. This practice leads to increased runoff velocities causing the formation of rills/gullies and the associated increase in erosion rates. Roughening of the slope reduces runoff velocities, reduces soil compaction, increases soil infiltration rates and provides micro sites that promote vegetation establishment.

Surface roughening can be accomplished by tracking slopes with machinery or simply placing logs and woody debris on the slope. Tracking is very effective at minimizing runoff and erosion and promoting vegetation, however, it must be done in the proper direction. The grooves left by the tracks must be horizontal (perpendicular to the slope direction), as vertical grooves would accelerate the runoff and increase the erosion. Michael Harding, CPESC from San Diego State University has found that sediment yield from slopes can be reduced by 55% following tracking with machinery (Pers. Comm. 2002).

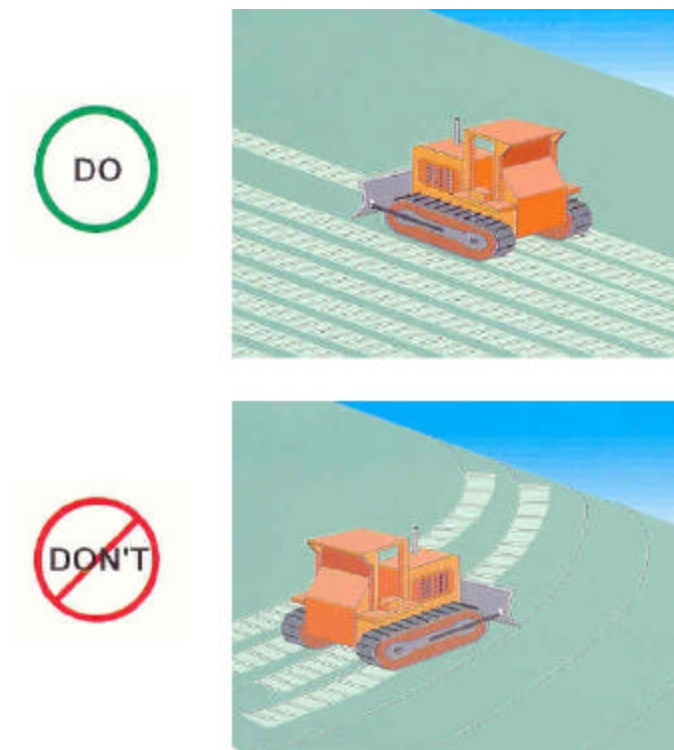


Figure 4. Proper tracking procedures. (California Regional Water Quality Control Board 1999).

Slope Benching

Slope benching involves the creation of flat surfaces, or benches, along the length of a slope. Slope benching provides many of the same benefits on a macro scale that are provided by surfacing roughening on a micro scale. Slope length and gradient are significantly reduced through this procedure, which, as previously described, reduces runoff velocities and prevents erosion. Benching can also enhance infiltration, as slowed water will have time to percolate into the soil. Benches can be constructed to divert runoff into adjacent vegetated areas by allowing for a slight gradient along the length of the bench. This method can be used if there is concern about initiating a slope failure at the bench as a result of excessive water accumulation. In most cases, benches constructed horizontally (with no gradient) are very effective at trapping sediment that that has eroded from the slope above, with minimal risk of slope failure.

Grass Seeding

Grass seeding is an excellent, cost effective method of rapidly establishing vegetation on exposed soils. Spreading grass seed over exposed soils that have the potential to erode into streams is easy and inexpensive. Grasses will provide protection to exposed soils from splash erosion; they will also reduce erosion by slowing runoff velocities, enhancing infiltration, trapping sediment and providing structural support for the soil. Grasses are typically effective over the short-term (five to ten years), as they will eventually die off. The goal is to provide this short-term remedy in the hopes that it will assist with the long-term goal of natural site revegetation.

Several varieties of grass seed are available that are suited for specific soil conditions and climatic regimes. It is important to pick the appropriate grass mixture for the desired goal and specific site conditions. Grass seeding should be done as soon as possible after works are complete in a given area. Although establishment success may depend on the time of year the seed was applied, it can usually be applied at any time of year with at least some success. Grass seed can even be applied over snow. The best times of year to apply seed are late fall and early spring. The least amount of success occurs when seed is applied during very dry periods and in the late summer when seeds will start to germinate, then die from exposure to frost.

Fertilizer may be necessary to promote establishment of the grasses when soil nutrients are limiting. Mulching (described below) is another way to promote establishment of grass as it provides direct cover and a warmer, wetter growing site.

Mulching

Mulching consists of spreading some type of material over exposed soils. Different types of mulch include straw, hay, woodchips, rock or hydroseed mulch. Mulch provides short-term protection of soil from splash erosion and should be done in conjunction with grass seeding. Note: grass seeding should be completed prior to the application of mulch.

It is important to sufficiently cover the soil surface with mulch, however; too much mulch can be detrimental. Straw/hay mulch should not be applied more than five centimeters deep for several reasons. Excessive thickness can be detrimental to the establishment of vegetation as it can trap too much moisture, block sunlight and provide habitat for rodents. High moisture conditions combined with a lack of sunlight promote the growth of mold, which can prevent the growth of vegetation.

Hydroseeding

Hydroseeding is an effective way to apply seed and mulch to large areas. Hydroseeding involves the use of a portable tank and pump that are used to spray the hydraulic mulch onto the site. Hydroseeding can include fertilizer to propagate rapid plant growth and tackifier to bind the components of the hydroseed mixture. Once applied, the tackifier binds the mulch fibers together, forming a net that protects the soil surface and the hydroseed material itself from splash, sheet and rill erosion.

Vegetation Planting

In addition to applications of grass seed, planting of larger, woody vegetation will aid in reestablishing vegetation on disturbed sites. The easiest, and most natural way of doing this is to set aside vegetation such as immature deciduous and coniferous species that are removed from a site during the clearing of overburden. The length of time it will take to replant the vegetation will determine what care is required to ensure survival of stockpiled vegetation. It may be necessary to plant high densities of good quality vegetation in a specified nursery area if it will be several months before vegetation can be replanted in its final location. Note: the roots of the vegetation must not dry out or the survival rate at the rehabilitated sites will be poor.

Bioengineering

Bioengineering is the use of live plant material to stabilize slope surfaces and prevent erosion. Bioengineering vegetation reduces erosion and acts as a sediment trap. Several different bioengineered structures can be installed to stabilize slopes and channel banks. Some more labor-intensive, aggressive structures, such as brush layers and wattle bundles, can be used to stabilize very unstable sites or sites in which erosion or mass wasting has already occurred. Probably the most broadly suitable and often implemented bioengineering method is live staking. This is the most simplistic type of bioengineering as it simply involves the insertion of live stakes into the soil matrix. While some structural support is immediately provided by the stakes, support will increase rapidly when the roots become established.

All types of bioengineering applications involve the use of live cuttings of certain varieties of deciduous vegetation. In the Yukon, willow and balsam poplar are the species typically used and are usually readily available in most areas. When a nearby source of these species is not available, bioengineering may not be feasible. Note: bioengineering using live cuttings must be conducted while vegetation is dormant.

Rolled Erosion Control Products

Erosion control products that can be purchased in rolls such as geosynthetic matting, erosion control blankets and open-weave textile meshes are very effective for the prevention of surface erosion. There are several different products available for several different applications. These products are typically made from straw, coconut fiber or synthetic material that is enveloped in plastic or biodegradable netting. They are well suited for long-term reclamation objectives as well as for temporary site stabilization. Several of the products are especially useful on steep slopes and stream banks that are very susceptible to erosion or slow to revegetate. Due to their effectiveness, these products are often used on slopes that are adjacent to sensitive areas such as streams.

For the full effectiveness of these products to be realized, proper installation procedures are very important. For example, prior to installation of erosion control blankets the surface upon which they are to be installed should be seeded as well as physically prepared to remove surface irregularities and reduce roughness. When laid out, the blankets must have uniform contact with the soil so that rill and gully erosion does not occur beneath the blanket. The blankets should then be well staked or stapled to the surface, ensuring that the stakes/staples are left flush with the surface.

Rock

The use of rock is very effective in terms of sediment and erosion control, but can hinder the return of natural conditions to the site, as vegetation will only establish in any gaps left between the rocks. Uses of rock include:

- Covering of slopes that are difficult to revegetate.
- Lining of erodible ditches.
- Weighing of the toe of slopes to prevent rotational slope failure.
- Protection of stream crossing structures.
- Scour protection at outlet areas such as culverts and drainage ditches.
- Streambank protection.

The minimum rock size required to armor an area must be determined prior to use to ensure that the rock used will not wash away. Larger flows and faster water velocities will require large rock sizes to ensure the effectiveness of the armoring.

5.3.3 Sediment Control

KEY CONCEPTS
<ul style="list-style-type: none">• Unlike erosion and runoff control, sediment control involves removal of sediment in suspension. It is much easier and cost effective to prevent suspended sediment from being entrained in water by implementing proper erosion and runoff control measures.• All sediment control activities require frequent inspection and maintenance.• Sediment control devices must be installed in locations that are easily accessible for maintenance and situated for the proper removal of the accumulated sediment.

Silt Fence

Silt fence consists of a woven geotextile fabric fastened to wood stakes. Silt fence is used to slow water velocities and allow sediment to settle out of suspension. Silt fence is most effective at capturing sediment that is being transported down a slope via sheet flow.

Silt fence is often mistakenly used as a means to filter sediment out of water, which is not its intended purpose. It is also not meant for placement across flowing water in ditches or channels. It is designed for installation along a **horizontal contour** along a slope or at the toe of a slope so that sediment is retained at the slope and will not move to sensitive areas. Properly installed silt fence can allow significant amounts of sediment to settle out and accumulate. As such, it is important to regularly inspect and maintain silt fence and remove accumulated sediment. Silt fencing should be used as a temporary sediment control measure due to the high maintenance requirements of silt fencing over the long term. The following points describe proper silt fence installation:

- The post must be on the downslope side of the fabric so that accumulated sediment does not push the fabric off the post.
- The fabric must be placed within a 15 cm trench (located on the upslope side of the fencing), which is then backfilled and compacted (Figure 5).
- If possible, silt fence should be located approximately 2 m away from the toe of a slope (to allow space for the sediment to settle out and collect).
- Silt fence must be constructed along the contour of the slope (Figure 5).

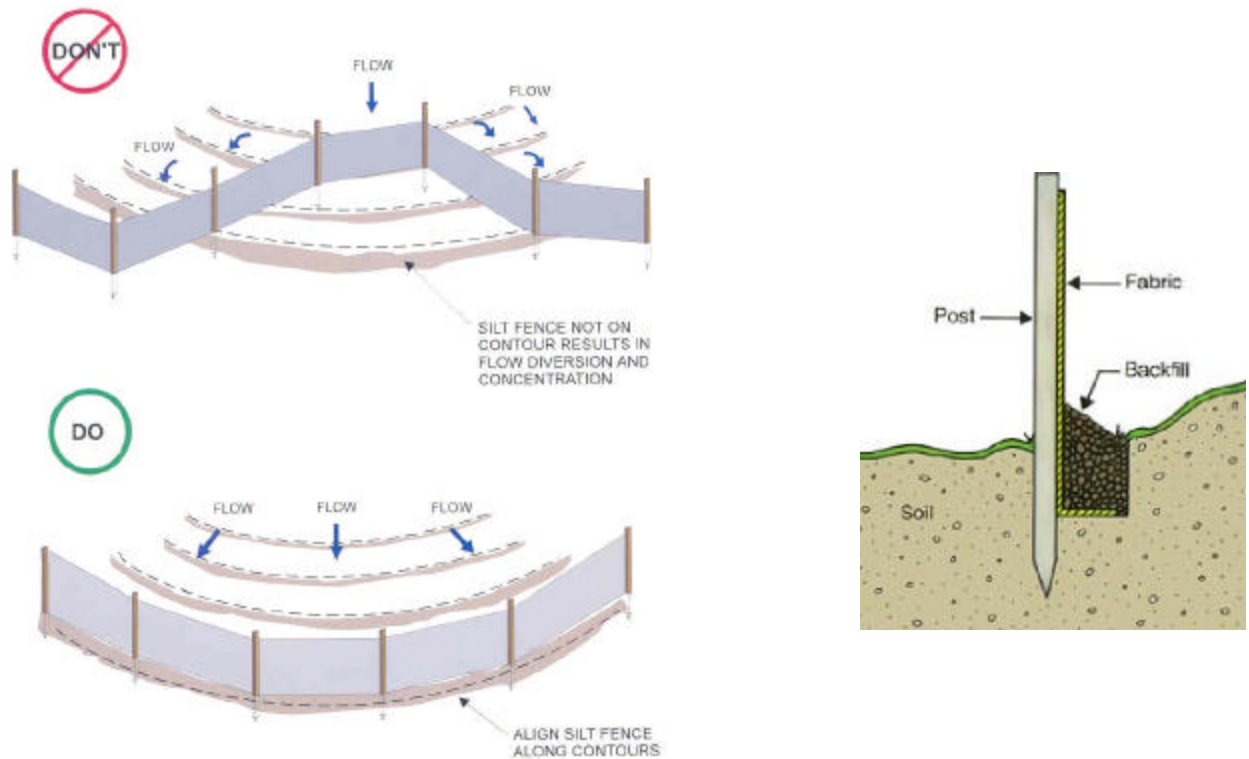


Figure 5. Proper silt fence installation (California Regional Water Quality Control Board 1999).

For Yukon placer mining activities silt fence is useful in retaining sediment within stockpiled overburden areas as well as at the base or across any erodible exposed slopes. Silt fence should not be used as a part of the final reclamation measures due to its maintenance requirements.

Straw/Hay Bale Dikes

In addition to silt fence, straw/hay bale dikes can be used along the toe of slopes to trap sediment by slowing water velocities. In contrast to silt fence, bale dikes can be placed across flowing water in ditches. Bales must be installed properly to function efficiently. The following criteria should be met for proper installation:

- They must be placed in a row with ends tightly abutted.
- They must be embedded in the soil at least 10 cm.
- Each bale should be anchored to the ground with two wood or rebar stakes that are driven to a depth of approximately 0.5 m.

Rolls of organic material such as a rolled up erosion control blanket or round burlap bags filled with organics can also be used in the same applications as the straw/hay bale dike. As with silt fence, the dikes require frequent inspection and maintenance. Trapped sediment should be removed when a depth of 0.2 m is reached.

Check Dams

Check dams are constructed in drainage ditches to slow water velocity and reduce ditch erosion. They can be constructed of rocks, logs, sand bags, straw bales or other materials. Check dams will allow some of the larger suspended sediments to settle out, so they must be properly maintained. Construction of check dams must ensure that water will not flow under or around the check dam. Water should only flow over the check dam without causing erosion of the banks of the ditch. As such, the center of the dam must be lower than its edges, which must be lower than the road surface.

Catch Basins

Catch basins are excavated pits designed to slow water velocity and settle out larger sediment particles. They are often constructed in the vicinity of cross drain culverts or near streams where there is a risk of ditchwater draining directly into a stream. Catch basins can be lined with fabric when constructed within permeable soils so that sediment-laden water does not leach out of the basin. Basic basin design should ensure that the basin is approximately three times longer than its width and is approximately 0.6 m in depth. Sediment accumulations must be removed on a periodic basis to ensure the basin's effectiveness.

Settling Ponds

Settling ponds are the most important sediment control structures in the placer mining industry. Extremely high sediment concentrations are present in placer mining effluent. Much of the coarser sediment can be removed by pre-settling pond sediment removal structures, but fine sediments can only be removed from the effluent through the use of properly designed and constructed settling ponds. Settling ponds are designed to slow water velocities enough that fine sediments will fall out of suspension so that water quality objectives of discharge into the receiving water can be met. Several settling ponds arranged in series are sometimes required to meet the water quality objective.

In addition to removing sediment from mining effluent, sediment ponds can also be used to clean sediment-laden runoff from excavated or stripped areas. Settling pond design guidebooks should be accessed to determine specific design criteria (for example see Nordin 1989, Rundquist et al. 1986 and others).

Pre-settling Pond Sediment Removal

Removal of sediment from effluent before it reaches the settling ponds can significantly reduce sediment concentrations in the effluent and increase the lifespan and effectiveness of settling ponds. Sediment removal prior to settling ponds can be accomplished by forcing effluent through coarse tailings and/or using pre-settling ponds. Pre-settling ponds are basically catch basins (described above) that are constructed along the tailrace (the channel that discharges effluent to the settling pond). Several pre-settling ponds can be constructed along a tailrace to further decrease sediment levels and ensure that ponding continues if one or more of the ponds are not cleaned out before they become filled in. Pre-settling ponds, however, retain only coarser sediment sizes (fine to coarse sands).

Forcing effluent through coarse tailings can remove up to 97 percent of sediment present in effluent, while pre-settling ponds can reduce the amount by approximately one half (Nordin and Latoski 1989).

The use of both methods will be very effective at sediment removal before effluent reaches the settling pond.

6.0 CONCLUSION: RUNOFF, EROSION AND SEDIMENT CONTROL IN YUKON

Many of the aforementioned erosion and sediment control methods have been used to date in Yukon. Some of the more aggressive measures, such as slope benching, grass seeding, hydroseeding applications, and extensive rock armoring have been used on highway and municipal projects. These aggressive, long-term measures are applicable to large projects that clear large areas due to the long-term nature of public infrastructure.

Specialized techniques have been used during projects that are located in sensitive areas such as stream crossings. These techniques include use of erosion control blankets, silt fence, planting of rooted vegetation, bioengineering and grass seeding. It should be noted that these techniques, as well as many others, are common practice in other jurisdictions and are becoming more commonly used in Yukon over the past few years. For example, with varying levels of success, a number of small projects involving the use of bioengineering techniques have recently been conducted in Yukon. In 2003, there are plans for a number of larger Yukon projects involving bioengineering techniques. The success of these projects will likely set the stage for the future use of these methods in Yukon.

The Yukon placer mining industry has used several types of erosion control methods such as settling ponds, and run-off control (ditching) as necessary components of day-to-day operations. In addition, miners are required to stockpile organic material from all clearing works for use in reclamation. This organic material has been used during reclamation activities to cover slopes and exposed soils, thus preventing erosion. Other erosion control techniques used during reclamation include revegetation, bioengineering and re-contouring of slopes.

The most effective type of erosion and sediment control that can be conducted by the placer mining community is planning. Generally, mining operations that conduct their works in a strategic manner have more success controlling erosion and reducing sediment inputs. Concepts that placer operations have used and should continue to develop during proper planning include:

- 1. Avoidance of sensitive areas.**
- 2. Reduction of the area that is to be cleared at one time.**
- 3. Reduction of the amount of time that areas are exposed to erosive forces by conducting reclamation of these areas as soon as possible after clearing.**

It is important to realize that specific site conditions will determine which methods are appropriate and when they should be implemented. Proper planning is the essential ingredient in the prevention and avoidance of unnecessary environmental degradation. Once properly planned, much of the environmental degradation often associated with placer mining operations can be avoided by implementing a variety of runoff, erosion and sediment control methods throughout the duration of the placer mining operation. Preventative methods will reduce the overall impact of the mine, improve public support of placer mining and reduce costs associated with reclamation activities.

One of the key concepts of runoff, erosion and sediment control is that there are often many different methods to achieve similar results. Obviously, as placer mining is often located in remote areas of the Yukon with difficult access, it is likely that many conventional methods such as hydroseeding will often not be practical. As such, placer miners are encouraged to use the runoff, erosion and sediment control concepts to develop innovative techniques of controlling erosion and sediment. As more emphasis is placed on erosion and sediment control in Yukon, people involved with on-site works will likely develop new technology and techniques. Innovative approaches in conjunction with existing techniques will form the basis of best management practices for placer mining in Yukon. As placer mining necessarily involves the disturbance of land that is often situated in sensitive riparian areas, efforts towards continual improvement of placer mining activities should continue to ensure that the best possible management practices are being implemented.

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