2000 Billings Land Reclamation Symposium

EVALUATING THE EFFECTIVENESS OF STREAMBANK STABILIZATION TECHNIQUES FOR REDUCING BANK EROSION ON THE UPPER CLARK FORK RIVER, WESTERN MONTANA

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ABSTRACT

Lateral channel movement on the upper Clark Fork River in western Montana has resulted in loss of valuable agricultural land and delivery of sediment and mine tailings into the river. In spring 1996, we initiated a study to evaluate the effectiveness of streambank stabilization techniques to reduce bank erosion. This study examines the effectiveness of 21 different bioengineering stabilization techniques used for reducing bank erosion on a large river system. The treatments incorporated a variety of materials; including container vegetation, willow (*Salix* spp.) pole cuttings, mature shrub transplants, log barbs, root wads, Douglas fir (*Pseudotsuga menziesii*) and Rocky Mountain juniper (*Juniperus scopulorum*) revetments, fascines, layered and non-layered coir (coconut husk) fabric, coir fascines, rock barbs, sod mats, gradient control, and riprap. Treatments were installed in fall 1996, spring and summer 1997, and fall 1998 on 23 areas totaling 1,735 m in length. Seven control reaches including 2,874 m of bank are also being monitored. 140 permanently monumented cross sections were surveyed before and after treatment implementation, after ice events in 1997 and 1998 for treatments established at that time, and after peak flow events in 1997 and 1998. Survival rates of various vegetative treatments were also monitored, and costs of construction for each individual treatment were calculated from detailed monitoring of construction activities. The 1996-97 and 1997-1998 ice events caused little erosion. However, the 1997 peak flow event caused substantial erosion of treatment and control banks. 1997 and 1998 peak flow erosion rates varied between treatments. Lateral migration rates for banks with treatments ranged widely from an erosion rate of 5.88 ft/year to a deposition of 0.5 ft/year. Three treatments (coir fabric and willow poles, Rocky Mountain juniper revetments and willow stakes, and container plantings alone) experienced very high rates of erosion (2.13, 3.65, and 5.88 ft/year). Six other treatments also experienced moderate levels of bank erosion in the years following treatment implementation. However, three treatments (sloped bank with coir fabric, container plantings and rock, coir fascine or willow/red-osier dogwood fascines), while untreated during the 1997 peak flow event, experienced very little erosion at all after the 1998 peak flow event compared to their pre-treatment erosion rates. The average erosion rates of the control sites from 1996-1998 varied from 4.6 ft/year to a deposition of 0.83 ft/year. A site established as a reference area for Clark Fork River erosion rates eroded at a rate of 0.02 ft/year. Cost of various treatment implementations ranged widely from a low of $5.58/ft to a high of $82.29/ft.

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INTRODUCTION

Like most rivers, the upper Clark Fork River naturally migrates across its floodplain. However, this rate of lateral channel movement appears to be accelerated above its natural rate. Factors contributing to an accelerated rate of lateral channel movement in the upper Clark Fork River watershed are difficult to identify. However, they can include changes in the uplands such as road building, timber harvesting, mining, and changes in the floodplain such as clearing for agriculture and development, grazing, and channelization by railroads and roads. Together these factors alter the timing, duration, and frequency of runoff and can prevent a river from naturally accessing its floodplain (Dunne and Leopold 1978). Accelerated lateral channel movement on the upper Clark Fork River has resulted in loss of valuable agricultural land and introduction of sediment and mine tailings into the river system.

In 1996, the Riparian and Wetland Research Program (RWRP) and ARCO Environmental Remediation, L.L.C. (AERL), initiated a streambank stabilization pilot study on the upper Clark Fork River. The objective of the study is to evaluate the effectiveness of various streambank stabilization techniques to reduce bank erosion. The treatments implemented in this study focus on bioengineering and the use of native riparian vegetation to stabilize banks instead of traditional "hard" treatments such as riprap.

STUDY AREA

Location

The study area is located in the upper Clark Fork River watershed in western Montana. Through most of the study area, bankfull widths range from 20–40 m, and the river can be described as a C4 channel (Rosgen, 1996). Typical treatment reaches consist of eroding, near-vertical banks ranging in height from three to seven feet above baseflow water levels. All treatment reaches are located on the concave (eroding) bank of channel meanders. The treatment reaches were not randomly selected as landowners requested assistance in stabilizing their banks. Since the treatment reaches were not randomly selected, the treatment reaches may not be representative of all the upper Clark Fork River banks.

Treatments

A total of 1,735 m of bank distributed across 23 areas on the upper Clark Fork River was treated between fall 1996 and December 1998. The treatments incorporated a variety of materials, including planted vegetation, log barbs, root wads, Douglas fir (*Pseudotsuga menziesii*) and Rocky Mountain juniper (*Juniperus scopulorum*) revetments, fascines, layered and non-layered coir (coconut husk) fabric, coir fascines, rock barbs, sod mats, gradient control, and riprap. Planted riparian vegetation included willow (*Salix* spp.) pole cuttings, mature shrub transplants, and container vegetation. The materials were arranged into 21 distinct combinations and include the following:

- coir fabric and willow poles
- coir fabric, willow poles, and log barbs
- coir fabric, rock barbs, rock toe, and container plantings
- coir fabric, willow and red-osier dogwood fascine toe, and container plantings
- coir fabric, coir fascine toe, and container plantings
- coir fascine toe and container plantings
- container plantings
- Douglas fir revetments and willow stakes
- Rocky Mountain juniper revetments and willow stakes
- mature shrub transplants and willow stakes
- root wads, mature shrub transplants, and container plantings; and
- rock barbs and mature shrub transplants
- layered coir fabric, container plantings, and coir fascine toe
- layered coir fabric, container plantings, vertical willow stakes and rock toe
- layered coir fabric, container plantings, and rock toe
- layered coir fabric, container plantings , root wads, and coir fascine toe
- layered coir fabric, container plantings, mature transplants, root wads, and rock toe
- layered coir fabric, container plantings, vertical willow stakes, and coir fascine toe
- gradient control installation
- riprap
- sod mats

An additional 2,874 m of bank in seven areas was also monitored as controls. Control areas were selected that were similar in location, adjacent land use, and bank height and structure to treatment area sites. One of these areas, a particularly well-vegetated area, functions as a reference condition for upper Clark Fork River erosion rates.

METHODS

Treatment Implementation

Construction was completed on five treatment areas (FW01-FW04, and DT01) in October 1996, on eight areas in March 1997 (FW01, FW04, PRA1, PRA2, and PRB1-PRB4), on three areas in July 1997 (WLA0, WLA1, and WLA2) and on nine areas in October 1998 (DL02-DL10).

All treatments were designed and implemented with the long-term objective of establishing vegetation, both woody and herbaceous, on the streambanks. The vegetation will help to stabilize the banks with its binding root mass and structural protection against the erosive forces of ice and water. Materials such as coir erosion control fabric, log barbs, cut conifer revetments, coir fascines, and rock were used to provide temporary protection until vegetation can establish. Following construction, the sites were fenced to allow the vegetation time to establish. Grazing is not precluded and may be used as a management tool to control weeds.

In order to determine the cost-effectiveness of each treatment in reducing bank erosion, the cost of equipment, materials, and labor expenses of the construction process during treatment implementation was closely tracked. Costs were tracked through daily logging of construction activities and through billing information provided by contractors. Costs associated with mobilization of equipment will vary depending on individual contractors and on distance traveled, and thus are not included. Project oversight costs by RWRP are also not included.

Monitoring

A total of 140 cross sections was established throughout the 23 treatment areas and monitored repeatedly over time. Permanently monumented cross sections were established at each site by placing 1.7 m long rebar into the floodplain on both sides of the river perpendicular to the flow every 17–70 m depending upon the channel width. For most study reaches, cross sections were spaced at a distance equal to the bankfull width of the respective study reach.

Cross sections were measured using protocols similar to those recommended by Harrelson and others (1994), Kondolf and Micheli (1995), and Rosgen (1996). Cross sections were measured at regular intervals with two-member teams using a laser level and graduated rod with laser detector. In all cases, at least 20 measurements were made between the bankfull indicators. The following features were also recorded at the appropriate stations for each cross section: left pin, left terrace, left bankfull, left edge of water, right edge of water, right bankfull, right terrace, and right pin.

All cross sections were measured at least once, but most were measured four times: after the 1996-97 ice event, after the spring 1997 peak flow event, after the 1997-1998 ice event, and after the 1998 peak flow event. Each cross section was also measured at least once before treatment implementation and at least once after treatment implementation.

Data Analysis

All cross sectional data was entered into a spreadsheet and then imported into a FileMaker's FileMaker Pro 4.0 relational database. Data for each cross section were standardized with the permanent left pin elevation, and the following computations were made: width, mean depth, cross section area, width/depth ratio, entrenchment ratio, estimated velocity, stress in the near bank region, and Manning's roughness coefficient.

RESULTS

Although relatively common in terms of its peak flow (6.67 year recurrence interval at the Deer Lodge gage [1,980 cfs] and 10 year recurrence interval at the Galen gage [1,210 cfs]), the spring 1997 flood was an unusual event because of its volume and duration. In stark contrast to the high intensity, high duration ice and peak flow events of 1997, the 1998 peak flows were less intense and peaked later. The 1998 peak flow also was shorter in duration than 1997, lasting approximately four weeks. The base flows however, occurred at a greater intensity than 1997. All treatment and control reaches experienced a significantly higher rate of erosion as a result of the 1997 peak flow event compared to the 1998 peak flow event.

Treatment Areas

Lateral migration rates for banks with treatments ranged widely from an erosion rate of 5.88 ft/year to a deposition of 0.5 ft/year (Table 1). However, despite the implementation of bank stabilization treatments, most treatments experienced erosion after the 1997 and 1998 peak flow events. The average rate of erosion for all treatments was 1.5 ft/year for the period from 1996-1998. All treatments experienced a significantly higher rate of erosion as a result of the 1997 peak flow event than due to the 1998 peak flow event or the 1997 or 1998 ice events.

Three treatments (coir fabric and willow poles, Rocky Mountain juniper revetments and willow stakes, and container plantings alone) experienced very high rates of erosion (2.13, 3.65, and 5.88 ft/year). Six other treatments also experienced moderate levels of bank erosion in the years following treatment implementation.

However, the WLA0, WLA1, and WLA2 treatments (sloped bank with coir fabric, container plantings and rock, coir fascine or willow/red-osier dogwood fascines), while untreated during the 1997 peak flow event, experienced very little erosion at all after the 1998 peak flow event compared to their pre-treatment erosion rates. Additionally, the coir fabric and sloped willow poles treatment appears to have experienced a minor amount of deposition since implementation.

Table 1. Lateral Erosion/Deposition Rates by Treatment

Reach	**Description**	**Erosion/deposition (ft/year)**
DT01	Rock barbs and mature transplants	-0.6
PRA1	Coir fabric and willow poles	-2.1
PRA2	Rocky Mountain juniper revetments and willow stakes	-3.7
PRB1	Container plantings	-5.9
PRB2	Mature shrub transplants and willow stakes	-1.3
PRB3	Coir fascine and container plantings	-1.8
PRB4	Coir fabric and willow poles	+0.5
FW01	Container plantings	-1.8
FW02	Coir fabric, willow poles, and log barbs	-1.6
FW03	Root wads, mature shrub transplants, and container plantings	-1.2
FW04	Douglas fir revetments and willow stakes	-1.5
WLA0	Coir fabric, rock barbs, rock toe and container plantings	+0.1
WLA1	Coir fabric, coir fascine toe and container plantings	0
WLA2	Coir fabric, willow and red-osier dogwood fascine toe, and container plantings	0
Treatment Average		**-1.5**
DT	Control	-0.5
BK	Control	+0.8
PRA	Control	-2.3
PRB	Control	-0.4
PRC	Control	-1.2
FW	Control	-0.3
WLA	Control	-0.4
WLB	Control	-0.4
WLC	Control	-4.6
Control Average		**1.1**
GP	Reference	-0.2

Control Areas

Erosion rates for areas established as control sites in Reach A and Reach B of the upper Clark Fork River were highly variable and ranged from a high of 4.6 ft/year to a deposition of 0.83 ft/year (Table 1). Control sites averaged an erosion rate of 1.08 ft/year.

Reference Area

A heavily vegetated river reach located in the Governor's Project demonstration could function as a reference condition for upper Clark For river erosion rates. The average erosion rate for this area from 1997-1998 was 0.02 ft/year.

Treatment Implementation Costs

Treatment costs ranged widely from a low of $5.58/ft for mature shrub transplants to a high of $100.03/ft for installation of a gradient control. The average treatment cost was $41.30/ft.

DISCUSSION

As expected, all treatments where vegetation was planted on the terrace away from the immediate bank (as in container plantings alone and mature transplants with willow stakes) and the bank was not adjusted (e.g. sloped), the bank continued to erode. Theoretically, this erosion would cease once the bank erodes to the point where the roots of the vegetation stabilize it.

Calculations for the WLA treatments (sloped bank with coir fabric, container plantings and rock, coir fascine or willow/red-osier dogwood fascines) indicate that in 1998, these treatments experienced substantially less bank erosion than they had in 1997 prior to treatment implementation. Additionally, the treatment of rock barbs and mature transplants (DT01) received only very minimal bank erosion as well.

It appears that each cross section of bank is affected by varying factors that contribute to its rate of erosion. Therefore, it may not be appropriate to directly compare control areas to treatment areas. However, it may be more appropriate to compare treatment banks to the same bank at pretreatment levels of erosion. In order to accomplish this, it would be necessary to monitor the banks for a full peak flow season before conducting treatments. It is also necessary to continue monitoring for several years in order to assess the effect of treatment on the rate of erosion under a variety of flow conditions. With this information, one would be in a better position to assess how individual treatments influence erosion rates by comparing the treatments to themselves and each other over time.

In general, treatments that required heavy equipment are less expensive than those that are labor-intensive. Treatments installed in March (spring) were more expensive than those installed in October or July (fall or summer), probably due to the high water and colder working conditions. Treatments which required substantial resloping of high banks (e.g., WLA1) are also considerably more expensive. Various treatments to stabilize the toe of the bank also affect the cost of the treatments. The costs of the seven layered coir fabric treatments ranged from $33.35/ft to $52.49/ft, with an average cost of $41.31/ft. These treatments all were structurally similar in that they contained a bank excavated to a 4:1 slope with coir fabric secured at the toe and then laid on a rock platform. Sod was placed on top of the fabric, and the fabric was then rolled back over the sod and stapled down. Main differences occur with the manner in which the toe was secured (rock toe or coir fascines) and in the vegetation used for stabilization (container plantings, vertical stakes, and mature transplants). Those treatments that used a coir fascine toe (DL02, DL05, and DL09) instead of rock toe (DL03, DL04, DL07, and DL08) had higher material costs. These treatments also used slightly more labor than treatments with a rock toe. Average cost of treatments using a coir fascine toe was $49.77/ft compared to the average cost of a rock toe ($34.99/ft).

The average cost of the treatments was $41.30/ft. However, when treatments are implemented on a large scale, costs should decrease. Factors such as substantial lead time to grow plant material or to work during the lowest water conditions, opportunities to order material in bulk, and lower mobilization expenses with longer treatment reaches should reduce costs. Familiarity with installation procedures can also contribute to reduced costs.

In general, those treatments that were implemented on shorter bank lengths seem to be more costly than similar treatments implement on longer banks. When implemented on the large scale, longer treatment reaches should reduce the cost per foot of each treatment.

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GEOMORPHIC DEVELOPMENT OF A RECONSTRUCTED SUBALPINE STREAM CHANNEL

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ABSTRACT

In the Fall of 1998 a stream channel was constructed at a coal mine reclamation site in west-central Colorado based solely on a geomorphic design. The project site was located at 8000 feet AMSL in a subalpine watershed that yields perennial streamflow primarily from snowmelt runoff. The native channel had a very coarse-grained substrate derived from infrequent debris flows. The reconstructed channel was built with native debris flow material having the same particle size distribution as the substrate of the native channel. The reconstructed channel was built to a nearly uniform 6.8 percent gradient and was approximately 1250 feet long, 40 feet wide, about 10 to 30 feet deep with a "pilot" channel that was about 14 feet wide and two feet deep. The reconstructed channel was built with virtually the same width, depth, gradient, and low sinuosity as the native channel upstream of the project site. Two channel surveys, one conducted immediately after construction and one after the 1999 runoff season, indicated that the channel bed experienced only minor vertical adjustments and no significant change to its substrate size distribution. However, step pools developed due to the redistribution of cobbles and boulders within the channel during high flow. The step pools in the constructed channel function and appear indistinguishably from the step pools in the native channel. The development of step pools resulted in a new thalweg gradient profile that varied from -10 percent to +50 percent. The highly variable thalweg gradient profile did not indicate a stability problem, because the native channel had a similarly variable thalweg gradient profile and there was no indication of channel incision. Also, the reconstructed channel did not appreciably widen or migrate laterally during the 1999 runoff season. The channel's configuration and coarse native substrate were critical to maintaining the channel's thalweg gradient and natural appearance. This project supports the simple notion that a reconstructed stream channel can function and appear like a native stream channel if only its basic morphometric elements (channel width, depth, gradient, and alignment) and substrate are restored.

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INTRODUCTION

In late Fall of 1998, members of the State of Colorado, Division of Minerals and Geology (DMG) and the U.S. Office of Surface Mining Reclamation and Enforcement (OSM) supervised the construction of an unusual perennial stream channel at the former "Coal Basin mine." The stream - Dutch Creek - is unusual, because it is located in a scenic subalpine watershed (see Figure 1) and the primary channel-forming agents are infrequent cobble- and boulder-laden debris flows (see Figure 2).

PROJECT AREA LOCATION AND SITE DESCRIPTION

The project area is located in a scenic west-central Colorado watershed, four miles west of Redstone, CO. Redstone is located approximately 21 miles west of Aspen, CO and 26 miles south of Glenwood Springs, CO. The project area lies between 7995 and 8085 feet AMSL (see Figure 1). Dutch Creek is a tributary of Coal Creek, which flows into the Crystal River at Redstone, CO. The project area once was a coal mine facility site constructed by leveling a debris fan near the mouth of Dutch Creek.

Geomorphic Setting

The Dutch Creek watershed lies between about 8,000 feet and 11,000 feet AMSL and has a total drainage area of approximately 4.1 square miles. The Mancos Shale that underlies this watershed has been thermally metamorphosed, giving it greater resistance to erosion than the relatively soft unmetamorphosed Mancos Shale. Accordingly, the Dutch Creek watershed is relatively steep. Cliff-forming sandstone units within the Mancos Shale are found near the watershed divides and provide material for infrequently occurring debris flows (see Figure 1).

Debris flow is the major channel-forming process for Dutch Creek and the entire Coal Creek watershed (Costa and Jarrett, 1981). Dutch Creek flows in a relatively small “pilot” channel ontained within the bottom of the much larger debris-flow channel (see Figure 2). Except for floods and rare debris flows, Dutch Creek flows within the “pilot” channel.

Flow Characteristics

Dutch Creek is a perennial stream that flows primarily in response to snowmelt runoff and secondarily to rainfall events and groundwater inflow (see Figure 3). Annual snowfall typically exceeds 200 inches at the project area. Rainfall in a high-elevation watershed such as this is typically far less intense than at lower elevations (Jarrett, 1990). Based on an extensive evaluation of USGS flow records, Jarrett (1987) found that Colorado streams above 2300 meters AMSL (7546 feet) produce a maximum unit discharge of 1.1 cubic meters per second per square kilometer. This maximum flow is 413 cfs at the mouth of Dutch Creek.

Figure 1 - The Dutch Creek Watershed and a portion of the project area.

Figure 2 - View of native Dutch Creek showing channel in coarse debris flow material. The design for the 1250-foot reach of Dutch Creek through the project area was based only on Geomorphic design parameters (see Pranger et. al., 1996).

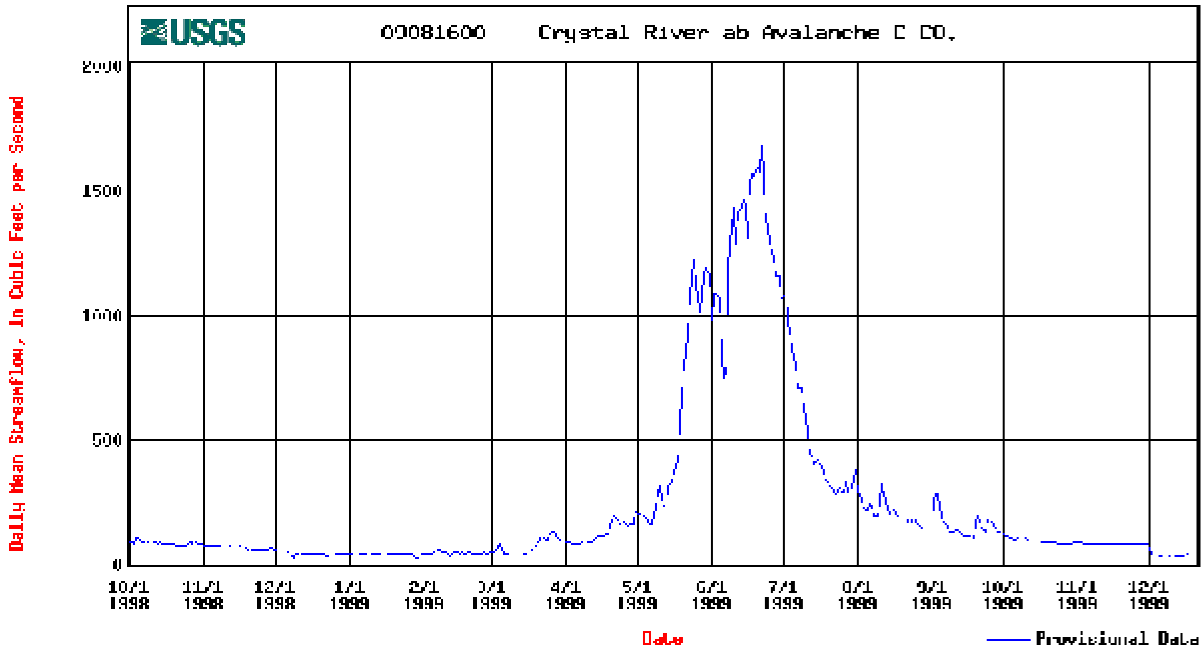

Figure 3 - USGS 1999 annual hydrograph for Crystal river seven miles downstream of the project area. Dutch Creek's hydrograph has a similar shape and is indicative of snowmelt runoff.

RECONSTRUCTED CHANNEL SUBSTRATE CHARACTERISTICS

Channel design characteristics were obtained from a 1750 foot long reference reach (see Harrelson et al, 1994 and Rosgen, 1994) of the native Dutch Creek channel located immediately upstream of the project area. The reconstructed channel was built with the same native substrate material and virtually the same width, depth, gradient, and low sinuosity as the native channel upstream of the project site (see Pranger et. al., 1996). The channel was surveyed immediately after construction and in late August 1999 to track the project's success (Kondolf, 1995; Kondolf and Micheli, 1995)

Wolman pebble counts were used to determine the substrate grain size distributions of the reference reach and the constructed channel (see Wolman, 1954 and Figure 4). The distributions are all relatively similar. The distributions all range from boulders to clay particles. The D_{50} for the native and reclaimed channels, respectively, was four and six inches. After the 1999 runoff season the distribution of material greater than about two inches in diameter in the constructed channel remained constant. However, the amount of material smaller than two inches was reduced. The channel transported the excess fine fraction out of the system. The coarser fraction remained virtually unchanged. The distribution in the constructed channel after the 1999 runoff season is a composite of the native and as-built distributions.

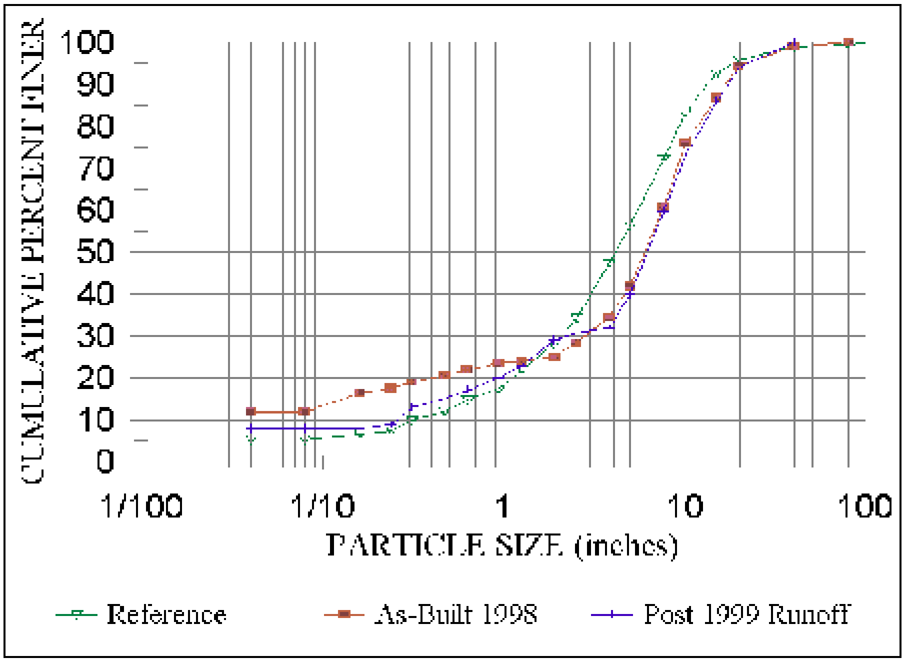

Figure 4 - Dutch Creek grain size distributions for the reference reach (Reference), the constructed reach immediately after construction (As-Built 1998), and the constructed reach after the 1999 runoff season (Post 1999 Runoff), based on Wolman pebble counts.

RECONSTRUCTED CHANNEL MORPHOMETRIC CHARACTERISTICS

The constructed channel had a fairly uniform 6.8 percent gradient, compared to 6.3 percent in the reference reach (See Table 1). The average gradient of the constructed channel was slightly higher than the reference reach due to spatial constraints in the project area. However, the channel stability was not decreased, because of the slightly coarser substrate material in the constructed channel (Figure 4). Also, the native channel width, depth, and sinuosity were closely approximated in the constructed channel. Images of the entire project area (Figure 5), the constructed channel (Figure 6) and the native channel (Figure 2) demonstrate that the channel had a natural appearance.

Parameter	Reference Reach Mean	Constructed Reach Mean
'Pilot' Channel Gradient (Percent)	6.3	6.8
'Pilot' Channel Width (Feet)	17.7	~14
'Pilot' Channel Depth (Feet)	1.6	~2
Channel Sinuosity	1.05	1.13

Table 1 - Morphometric comparison of the reference and constructed reaches of Dutch Creek.

Figure 5 - Overall view of the reconstructed Dutch Creek channel.

Figure 6 - Example reach of reconstructed Dutch Creek channel. Notice step pools.

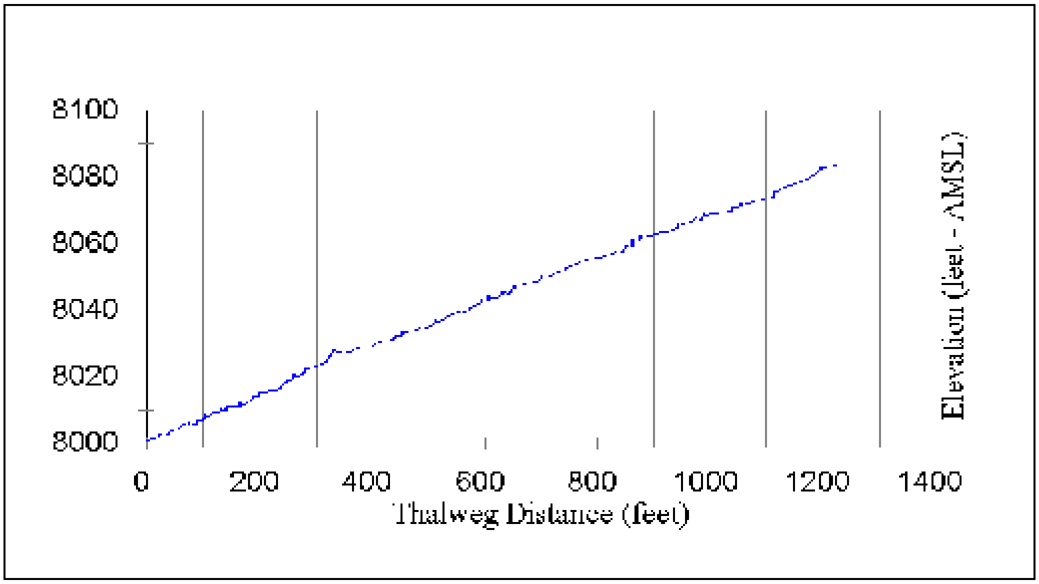

Figure 7 - Reconstructed Dutch Creek thalweg profile. Small undulations are step pools, except for the one at a distance of about 340 feet, which is a temporary road crossing.

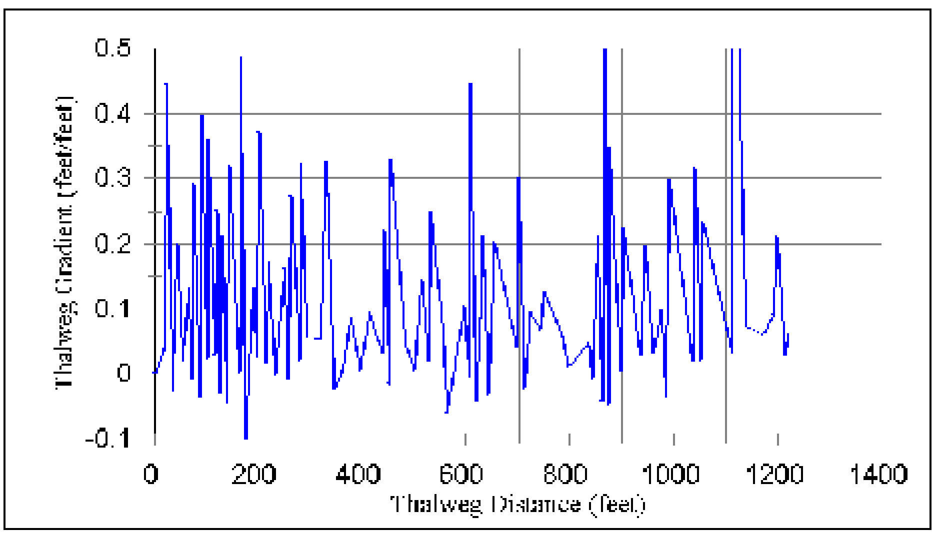

Figure 8 - Reconstructed Dutch Creek thalweg gradient profile after 1999 runoff season.

The profile of the reconstructed channel thalweg after the 1999 runoff season indicated that the channel bed experienced only minor vertical adjustments (Figure 7). The minor vertical adjustments are step pools that developed from the redistribution of cobbles and boulders within the channel during high flow (Figures 6 and 7). The step pools in the constructed channel function and appear indistinguishably from the step pools in the native channel. The development of step pools resulted in a new thalweg gradient profile that varied from about -10 percent to +50 percent (Figure 8).

The highly variable thalweg gradient profile did not indicate a stability problem, because the native channel had a similarly variable thalweg gradient profile (see Pranger et. al, 1996) and there was no indication of channel incision (Figure 7). Also, the reconstructed channel did not measurably widen or migrate laterally during the 1999 runoff season. Stream channel instability is indicated when a stream is: 1) aggrading; 2) degrading; 3) changing bed material particle sizes; 4) changing the rate of lateral migration through accelerated bank erosion; and/or 5) changing morphological type through evolutionary sequences (Rosgen, 1995). This channel has not changed its stream type (a Rosgen type A3 channel), and has no visible signs of instability.

IMPLICATIONS OF THE PROJECT

The channel's configuration and coarse native substrate were critical to maintaining the channel's thalweg gradient and natural appearance. This project supports the simple notion that a reconstructed stream channel can function and appear like a native stream channel if only its basic morphometric elements (channel width, depth, gradient, and alignment) and substrate are restored.

This project was successful, because the channel's shape and substrate materials were essentially restored to "native" geomorphic conditions. By restoring the shape of the channel, the hydraulic and gravitational forces causing erosion were maintained. By restoring the substrate materials of the stream, the forces resisting erosion were reestablished (see Schumm and Harvey, 1993). This approach met a key goal of shortening the time required for the channel to reach its "equilibrium morphology" (Jackson and Van Haveren, 1984). The equilibrium morphology of this channel included step pools that were best created by natural streamflow. This channel was built with simple morphometric and sedimentologic approximations that were sufficient to ensure a natural appearance and stability equal to the native channel. The initial field evaluation of Dutch Creek's response after construction validated the geomorphic channel design approach.

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INTRODUCTION

The question - to reclaim or not - is no longer relevant. Every reputable mining company, the EPA, state highway departments, and other industries or government agencies attempt to rehabilitate to some extent the lands they disturb or the lands within their jurisdiction. The question today is what is adequate reclamation.

A definition of reclamation is appropriate at this point. Reclamation is the goal of returning the soil and the plant community it supports to conditions in which the stability and productivity of the site are comparable to that of the site prior to disturbance. Reclamation includes components of hydrology, soils and vegetation. Arguments that disturbed sites should be returned to pre disturbance conditions aren't relevant because it is not possible to do so.

We cannot restore a site even after an action as simple as plowing because of all of the changes produced in the soil physical, chemical, and biological properties by the action of turning over or mixing the top six inches of the profile. However, we can revegetate the site to some or most of the plant species found on the site prior to disturbance by very careful and selective reclamation. Whether this is called restoration or reclamation is not relevant, it is simply academic and I prefer to use the term reclamation. Many researchers call this type of reclamation restoration but as Allen (1995) pointed out, "...even the best examples of restoration have been able to reintroduce only a fraction of the plant species richness and natural recolonization is slow at best."

In the late 1960's and early 1970's western coal mining was bursting out of the constraints imposed by transportation costs and cheap eastern coal because of the growing demand for energy and air pollution awareness. The Arab oil embargo simply exacerbated the demand for western coal. At that time the potential for returning livestock to range sites after they had been surface mined was not considered good. Curry (1975) for example was quite skeptical that Great Plains minesoils would ever be productive after stripmining. Today we know that livestock gain weight and reproduce as well on reclaimed mined lands as they do on native range. We know that the land can be as stable as it was before disturbance and that wildlife invade the land even before mining is finished. These generalizations pertain to reclaimed mountain soils as well as reclaimed soils on the plains.

We now have thousands of acres of western land that was disturbed by surface mining in various stages of reclamation. Some of this land has been supporting crops or livestock since before the Surface Mining Control and Reclamation Act was enacted in 1977 but little of this land has received approval as successfully reclaimed. If the soils and vegetation were considered successful, then one would assume that final and complete bond release would be authorized. This has rarely been the case on coal mines in our region and I do not know of any superfund sites that have met with widespread approval after rehabilitation. Therefore I must assume that the reclamation of these sites is lacking in some quality.

THE QUESTION

The big question today at mines, superfund sites, linear rights-of-way, and other disturbances is, are the results of reclamation good enough for final approval be it as full bond release on coal mine sites or some other criteria that signifies adequacy at a superfund site or along a highway right-of-way. For various reasons many agencies (e.g. EPA), advocacy groups, and others are attempting to apply the final bond release criteria of SMCRA to disturbances of interest to the group, therefore, I shall use the success criteria of this law as the basis for my discussion. But, please be aware that what I am about to say pertains to the determination of reclamation success on all forms of surface disturbances in the semiarid west.

In an attempt to answer this question of successful or unsuccessful reclamation a group of terms were introduced into the Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87). These include diversity, production, self perpetuating, native, and succession among others. All of these terms pertain to the plant community growing on the disturbed site and all have shortcomings that lessen their ability to quantify successful reclamation. This I believe is the cause of our inability to document successful reclamation. Our definition of successful reclamation is based on ambiguous terms or on ideas and concepts that we have not fully considered. I will attempt to illustrate this.

Diversity

The first of these terms was ‘diversity’. As several authors have pointed out this term has almost as many definitions as individuals attempting to define it (Chambers 1983, Whittaker 1975, McIntosh 1967). It definitely is not species richness, or simply the number of species within a predetermined area because diversity includes some intangible reference to the distribution and number of each species. This is what makes it so hard to quantify, these intangibles. In addition to this weakness if we carefully inspect undisturbed environments we find that in areas of uniform soil, slope, aspect, and exposure the number of species is surprisingly small. The reports of large numbers of species are always from more mesic areas to the east or if from our region then they are from disturbed sites, grazed sites, or landscapes of diverse soils, slopes, aspect, exposure, etc. But, both federal and state law or regulation require that those disturbing a site reconstruct a uniform soil of relatively constant slope on the site after the disturbance. How can the individual responsible for reclamation produce a diverse plant community on a disturbed site, even if we could define it, when they are restricted to a uniform environment? As Prodgers and Keck (1996) so apply pointed out habitat is one of the critical keys to vegetational diversity.

Production

Production was the second term I mentioned. In every instance in which a report describes the production measured on a disturbance the parameter measured was actually standing crop not production. Production is the amount of tissue produced by the plant not the amount of above ground biomass that was measured after a number of herbivores have chewed on the vegetation. Production should include the underground component of the plant. This is rarely measured. But in terms of site stability it is probably more important that above ground biomass. Several years ago Rich Prodgers carried out a vegetation study in the area of a proposed coal mine near Circle, Montana. In one year of sampling he recorded between 10 and 20 lb/a of standing crop. On the same transects he recorded almost 2,000 lb/a the next year. A plant parameter that varies over two orders of magnitude from one year to the next is not a reliable interpreter of revegetation success.

Self Perpetuating

Many groups and individuals ask if the vegetation growing on a disturbance is self perpetuating. Federal and state laws or regulations state that vegetation on coal minesoils must be 'self perpetuating' or 'self regenerating'. I presume this means the plants must be reproducing themselves. This can not be addressed other then stating that the plants are forming seedheads because there are no safe sites for new plants to develop on young minesoils for many years after the original seeding. The following example illustrates this principle.

Area to be reclaimed: One acre

Seed Mix:

	Rate (PLS)	
Grasses	Seeds/ft^2	lb/a
Western wheatgrass	4	1.5
Blue bunch wheatgrass	4	1.5
Needle-and-thread	4	1.5
Forbs		
Purple prairie clover	2	0.3
Prairie coneflower	2	0.1
Black sampson	2	0.6

If we assume that half of the seed germinates and establishes there remain nine plants on each square foot of soil. There are neither adequate nutrients nor sufficient water to support that number of rapidly growing plants. By the time of review for determination of adequacy of reclamation there are probably only one or two plants surviving on this foot of minesoil. Which plant will it be. Probably the one with the genetic constituents that enable it to utilize the resources of the site rapidly before another plant can absorb them and the plant lucky enough to find these nutrients and moisture. That is, the most competitive and tolerant of the seeded species. We are selecting cultivars for exactly those reasons. We want the new plants to be rapid growing and tolerant of the cold and drought of our prairies and mountains. They do this so well they absorb most of the nutrients and moisture in the soil and leave little for most other plants of the system.

What is the life expectancy of these plant on the Great Plains? We do not know exactly but we know that it is 10 years for some of these species and probably much longer than that, possibly several decades, for many of the perennial grasses. Since our seeded area has produced the maximum number of plants permitted by the soil and climate of the area there are no safe sites for seeds to germinate and establish. How then can the investigator state that new plants are establishing on the site. The new plants cannot enter the ecosystem until one of the older plants dies and this will not occur for many years. The investigator can state that the plants growing on the disturbed site are setting seed and there may be a young plant or two but it is rare that it can be definitely stated that new plants have established from seed produced by the plants growing on the reclaimed site.

Native

Vegetation seeded on disturbed sites is to be composed predominately of native species. The reason given for this regulation is that natives are better adapted to the rigors of our soils and climate than introduced species. That isn't necessarily true and is becoming less so each day as more and more exotic plants invade our native grasslands. If it were true we would not have so many noxious weeds and few plants are as well adapted to the west as Crested wheatgrass (Walker et al. 1995). Introduced species may be undesirable but lack of adaptation to the site, low forage production, or lack of palatability can not be used as rejection criteria.

Succession

Finally, new plant communities growing on disturbed sites are supposed to be undergoing succession. Succession is defined as the progressive changes in vegetation and animal life that culminate in the climax plant community. Succession is readily observable during the first few years of plant growth on disturbed sites. Let us say three to five growing seasons as the annual weedy species that rapidly invaded the new plant community during its first growing season are replaced by the very aggressive, perennial, stress tolerant cultivars in the seed mix. During the next undetermined number of years very few changes occur in the plant community. Possibly a few tough weeds invade it, possibly two or more seeded species disappear from the community but the anticipated invasion of the site by propagules from adjacent rangeland does not occur in any great amount during anything close to the bonding period. Observations have not shown a return to anything like original vegetation on semiarid grasslands even when grazing is excluded (Laycock 1991, Allen 1988).

Successional concepts as developed in the more mesic coniferous forest of the west or in the more mesic east occur at such a slow rate on the plains that the changes cannot be measured in a few decades. We have no idea what final climax vegetation would look like on the Northern Great Plains and the foothills of the Rockies. What European man found when he arrived in the west was an ecosystem maintained by burning and grazing. This system was never allowed to develop to a climatic climax but was maintained in a fire climax. Lewis and Clark (Ambrose 1996) noted the large fires used by the native Americans to mark the flotillas progress westward and fire was also used by the American Indians to remove vegetation surrounding winter villages. As early as 1793 fires on the Northern Great Plains were noted. Fidler (1793) said, "These large plains either in one place or another is constantly on fire..." He further noted that, "The lightning in the spring and fall frequently lights the grass, and in winter it is done by the Indians." These were not small fires. Haley (1929) gave an account of a fire in

1885 that started in the Arkansas River country of western Kansas and burned 175 miles to the Canadian River Breaks of Texas. He also gave accounts of several large fires of 20 by 60 miles.

Clearly fire and climate are the major factors controlling vegetation on the Great Plains (Wright and Bailey 1980) and many authors maintain that fire is the reason why the Great Plains are treeless (Stewart 1953). Which stage of succession are the reclamation programs of the Great Plains to strive to create - the unknown climax, a forested stage, some seral grassland stage, or none at all. Many say establish what was there prior to disturbance. With the exception of plowed crop land most of the acreage disturbed by mining and linear rights-of-way on the Great Plains is native rangeland. But, this vegetation is a midseral stage of succession, a disclimax maintained by burning and grazing. If this is what we want than we in fact do not want succession to take place.

Clearly we need better criteria for reclamation success or final bond will never be released on many acres of western surface mined land. Reference areas or technical standards have value and should be incorporated into these new criteria but the terms mentioned above have serious shortcomings.

A POSSIBLE SOLUTION

If the soils, land forms, and hydrologic balance of the disturbed site have been rehabilitated and an approved seeding and planting has taken place what final criteria should be evaluated to determine reclamation success. Obviously, a thousand years of stable soil and vegetation production would be a good answer but not a realistic one. Some set of parameters must be defined to answer this question and they must be applicable within a reasonable amount of time. In our region the ten year bonding period of SMCRA is a reasonable starting point for a reclamation time frame.

For all disturbances from highway meridians and shoulders, through all types of mining, to hazardous and non hazardous waste disposal sites vegetation cover has been the parameter evaluated for determination of final reclamation success. At best this analysis has been a contentious determiner of reclamation success and in the worse case vegetation is simply not acceptable as the determiner. The best case occurs on surface coal minesoils with all of the problems noted above obstructing a clear definition of reclamation success. The worse case occurs on hazardous waste sites on which vegetation can be readily grown but is of questionable longevity. Rather than placing total confidence in plant performance I would like to propose that we give a better look at the soil profile than is presently advocated. The rootzone is less influenced by perturbations in the weather and several characteristics of this soil layer may be more clearly defined and evaluated than vegetative parameters. If the surface soil horizons express certain characteristics vegetation will develop on and in it whether intentionally seeded or not. Vegetation is in reality a visible reflection of the attributes of the rootzone. I shall discuss several attributes of soil on a disturbed site which might be evaluated to determine reclamation success.

Topsoil

Coal mine regulations necessitate that topsoil be salvaged and saved for application to recontoured minesoils, but, both the quality and quantity of this material are important to a functioning soil system. Stored topsoil may be degraded and require some type of rejuvenation after application to the disturbed landscape to quickly regain its predisturbance plant supporting capacity. The coal industry has rapidly learned how to maximize recovery and minimize destruction of this valuable resource. Highway departments have been slow to maximize recovery of better surface soils and still often spread poor quality material for topsoil along meridians or shoulders. The EPA, Forest Service, Bureau of Land Management, and state Abandoned Mines Programs often find themselves without any topsoil at disturbed sites under their jurisdiction. At these sites the construction of good quality topsoil may be accomplished but it is expensive and time consuming. Nevertheless, the importance of this soil layer to the performance of vegetation cannot be overstated. The quality and quantity of topsoil directly influence the germination, growth, production and reproduction of plants (Barth and Martin 1982, Doll et al. 1984). The quality of topsoil can be defined by determination of the chemical, physical, and biological characteristics of the material.

Biological System in the Soil

Organisms within and on the soil represent an integral component of a functioning soil system. While concentrated in the topsoil cover they also extend in limited quantity into lower horizons. They range from the small bacteria to animals as large as earthworms and small rodents. The major types and ranges of their numbers are available. The larger animals initiate the decomposition of plant and animal tissues by pulverizing, granulating and incorporating these materials within the soil. The smaller invertebrates and worms continue the process by degrading large organic materials to smaller pieces. Finally bacteria, fungi, and actinomycetes complete the conversion of large organic molecules to carbon dioxide, water and nutrients. All of these organisms are, therefore, indispensable in a healthy soil. Trends in the populations and species of these organisms can or already have been established. Decreases in the number of species precede degradation of plant communities. On coal mine sites when direct haul topsoil in applied to recontoured minesoils populations of these organisms are maintained or recover rapidly. When stored topsoil is spread on a site these numbers have been reduced. On polluted soils of many superfund sites the number of species are markedly reduced (Hartmen 1973) but construction of a new topsoil may raise their numbers.

Chemical System in the Soil

The enumeration of all of the chemical reactions in the soil is impossible but several major components of these reactions may be measured and serve to indicate that the disturbed soil has or is in the process of recovering from disturbance. Like the biological components of the soil system these reactions are concentrated in topsoil but they also occur to greater or lesser degrees in lower horizons. Parameters such as the infiltration rate and water holding capacity, cation exchange capacity, organic matter content, and concentrations of the major and minor nutrients are of major importance to a healthy soil system.

On coal minesoils the characteristics of materials in the top four feet of the profile are carefully regulated but such is not the case on superfund sites or hardrock mine wastes. At these latter sites the presence of materials with low water holding capacity or elevated levels of alkaline, saline, or acid generating materials within the top four feet of the soil profile are common. It may be as subtle as sandy materials with inadequate number of exchange sites to prevent leaching of nutrients or selenium leaching into ground water from surface layers; it may be an obvious problem such as acid generation in the cap on a tailings pond. These soil deficiencies may not even pose a problem within a reasonable amount of time (10 years). They may not be detectable without special studies but preliminary determinations can indicate their possibility and prevent construction of soils possessing these attributes. The presence of low cation exchange capacity and coarse textured materials or detrimental soluble trace element concentrations should be enough to prevent declaration of reclamation success even though plant growth on the soil surface may meet all success criteria as defined by pre-reclamation agreements.

Depth of the Rootzone

The Office of Surface Mining has already addressed this problem. Federal and most state regulations clearly state that a non-toxic layer of soil at least four feet thick must be laid over recontoured coal mine disturbances. Montana requires eight feet of this non-toxic material. Numerous range plants and many woody species commonly develop roots deeper than four feet. A toxic layer at four feet hinders the establishment or presents an obstruction to the long term persistence of these species on prairie or mountain soils.

The depth of non-toxic material is especially important at numerous superfund and abandoned mine sites across the west. The use of an 18 inch coversoil over toxic material has been demonstrated at Butte and a few other locations with phytotoxic surface materials. The limitations of this type of reclamation are obvious: few species composing the plant community and a continuing maintenance problem. The more subtle problems with this reclamation are not so obvious. Is the development of new soil on these sites compensating for soil loss? Is this what we want to call successful reclamation?

SUMMARY

This discussion was not intended to be a condemnation of any existing system of reclamation success determination but simply a suggestion that looking at other facets of the reclaimed landscape might provide a faster and better determinant of final reclamation success. Obviously, something is wrong. At one of the few coal sites approved for final bond release in Colorado a massive land slide wiped out many years of excellent plant growth. On the other hand many acres of livestock supporting minesoils in Montana have been awaiting final bond release for over a decade because they do not meet some minor determinate of reclamation success. At superfund sites the growth of three or four acid and metal tolerant species on 18 inches of coversoil over toxic wastes is considered successful reclamation despite the lack of topsoil and an adequate root zone. We should reevaluate present success criteria and develop a realistic set of parameters to be measured for final determination of reclamation success.

The vegetation growing on our prairie and mountain soils are the result of centuries of slow weathering, plant growth, grazing, regrowth, fire, and again regrowth. Every time they are disturbed they change. If you drive a vehicle across the prairie during the wet season the tracks of the vehicle are visible for many years. Plowed fields returned to grazing in the 1930's still do to support vegetation comparable to that found on adjoining non disturbed areas. Yet, we expect a minesoil to support vegetation comparable to that on the site prior to disturbance. At the same time in our haste to cover the scars of past mineral exploitation in our mountains we pull a few inches of non-toxic material over the disturbance and call it reclaimed. Somehow these two extremes do not mesh. There should be some middle ground, some criteria that indicate that in the long run things will continue to improve even though the site will never get back to what it was before disturbance. Yellowstone National Park will never be the same as it was before 1988 but it is improving daily. The vegetation and soils along many of our highways, on numerous minesoils, and around some superfund sites are also improving daily. We should be able to distinguish those that are improving, those that are successfully reclaimed, or those changing in a manner that suggests that they are successfully reclaimed and separate them from those sites that are destined to fail. I believe that looking into the soil profile is a step in the right direction.

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2000 Billings Land Reclamation Symposium

RECONSTRUCTION OF A SUBALPINE STREAM CHANNEL WITH THE AID OF OSM'S TIPS TECHNOLOGY

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ABSTRACT

In the Fall of 1998 a 1250 foot long reach of a stream channel was constructed at 8000 feet AMSL in a subalpine Colorado watershed. The channel consisted of a "pilot" channel flowing within a larger debris flow channel. The tasks of creating a construction map and guiding the heavy equipment operators relied largely on the U.S. Office of Surface Mining's (OSM's) Technical Information Processing Systems (TIPS) technology. The construction map was a one foot contour interval cut and fill map overlain with a 10-foot grid. The cut and fill map was created with TIPS surface modeling software by subtracting the design map from the previously existing ground surface map. A TIPS Global Positioning System (GPS) data recorder was used to locate and stake the zero cut and fill contour lines onto the surface of the project area. The stakes were marked with the required slope gradients and cut and fill depths for the heavy equipment operators. After the grade of the larger channel was established, the outline of the "pilot" channel was staked, again using the GPS recorders as a guide. The "pilot" channel was excavated two feet into the larger channel. During construction, unanticipated spatial constraints required a rapid adjustment to construction maps for the upper 400 feet of the project area. Additional surface data points were gathered with the GPS data recorder in order to modify the existing surface, design and cut and fill maps. Revised maps were created in two days. The upper project area was subsequently staked according to the revised cut and fill map without any interruption to the heavy equipment operators. The entire project was completed in six weeks just before heavy snow fell. The rapid field adjustments were made easy with the TIPS technology. The successful construction of this sensitive excavation project demonstrated a viable alternative to standard surveying methods.

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2000 Billings Land Reclamation Symposium

THE NEED FOR PROPERLY RECLAIMING EPHEMERAL CHANNELS AND ASSOCIATED SIDESLOPES IN LANDS DISTURBED BY STRIP MINING

Herb Rolfes[1] and Steve Regele[2]

ABSTRACT

Ephemeral channels are often the most commonly encountered and hydrologically important features to replace in reclaimed, arid landscapes. They are the foundation for the postmine topography, the design of which requires input from multiple and overlapping natural resource disciplines. Despite this, reconstructed channels and sideslopes all too often do not closely resemble premine dimensions. Channel construction designs generally do not incorporate the overall hydrologic significance of these features, nor take into consideration criteria necessary to reestablish vegetative diversity and production, and wildlife habitat. Channels are often located along former haulroads, with insufficient thought given towards proper size and shape, blending the channel into sideslopes, or creating a meandering pattern. Channels are frequently reclaimed as broad swales, even though they may be replacement features for coulees or small, incised channels. Although broad swales may be relatively stable once vegetation becomes established, the initial lack of vegetative cover, and absence of meanders, often results in severe erosion and undesirable hydrologic effects, such as the formation of braided channels. Concurrent concerns are limitations on restoring appropriate and diverse vegetation and wildlife habitat when features such as coulees and small, incised channels are replaced with broad swales. The value of replacement features such as snow catchments that will hold and retain moisture, as well as areas wherein wildlife can take shelter from sun, wind and observation are often lost when appropriate channel and sideslope features are not considered during reclamation.

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INTRODUCTION

Ephemeral channels are often the most commonly encountered and hydraulically important features to replace in reclaimed, arid landscapes. As noted by Tarquin and Baeder "The design and reconstruction of lower (first and second) order stream channels presents a unique problem since these channels comprise the majority of the total stream length on premining surfaces and usually occur on the steepest slopes (1983)." The importance of ephemeral channels is based not only upon the sheer number of ephemeral channels, and their contribution to overall drainage density, but also in the role channel and sideslope features play in creating microsites for vegetation and wildlife.

Drainage channels are a very dynamic part of any landscape, and have significant influences on ecosystems and hydrologic systems. These facts are an important consideration in reclamation of drainages in drastically disturbed lands. Drainages must be reconstructed to pass water into, through, and off the disturbed area. Reconstruction of drainages must be compatible with protection of the hydrologic balance, the reestablishment of essential ecological functions, and the proposed post-mine land-use goals.

Concave longitudinal stream profiles are necessary to establish dynamic equilibrium, thereby reducing erosion, and are directly applicable to the design of a stable postmining topography (Bishop, 1980). Watershed divides may need to be adjusted, but the approved post mine topography should closely represent what existed in the premine state. Usually, this is accomplished through a comparison of premine and proposed postmine contour maps, noting the location, lengths and orientation of each channel and respective watershed areas. It is widely accepted, and important to the postmine hydrologic and ecologic function, that the postmining drainage density be at least equal to what existed premining [Bauer (1980), Stiller et. al., (1980), Bishop (1980), Gregory et. al. (1987)] and that channel sinuosity comparable to premine be restored [Shields et. al., (1995a), Welford (1993) and Bishop, (1980)].

Since all of these factors must be considered in the evaluation of ephemeral channel designs, input from multiple and overlapping natural resource disciplines is required. This can make the design of drainage channels in land disturbed by strip mining challenging, and complex.

REQUIREMENTS

Montana rules and regulations require that the; Design of reclaimed drainages must emphasize channel and floodplain dimensions that approximate the premining configuration and that will blend with the undisturbed drainage system above and below the area to be reclaimed. The rules further go on to state that; ...the channel and floodplain must be designed and constructed to … establish or restore the drainage channel to its natural habitat or characteristic pattern with a geomorphically acceptable gradient as determined by the Department," to; "… allow the drainage channel to remain in dynamic equilibrium with the drainage basin system without the use of artificial structural controls unless approved by the Department, to; "…improve upon unstable conditions which existed in the drainage system prior to mining where practicable in consultation with and upon approval by the Department," and to; "… restore, enhance where practicable, or maintain natural riparian vegetation in order to comply with …" revegetation and postmine landuse requirements and standards.

EVALUATION AND GOALS

The operator will need to evaluate channel and sideslope features that exist premine. This evaluation should take into consideration that, as noted by Pinet (1997), channels are not "things in space" but rather "processes through time." Once the channel is evaluated, and criteria such as area of the postmine drainage basin and revegetation and habitat restoration plans are known, the appropriate channel size and shape can be formulated, as can complementing sideslope features. A detailed examination of characteristics of each premining drainage channel to be disturbed may not be necessary with the approval of generic designs. As noted by Goodwin (1999), the classification of channels based on relative and absolute size factors may prove especially beneficial for reclamation purposes.

Derivation and application of some generic channel design criteria may be acceptable due to the nature of strip mining. Preceding actual mining, vegetation and soil, as well as overburden, is removed from most, if not all, of the drainage basin. Only after the coal is removed will the area be backfilled, regraded, topsoiled and seeded. Due to the drastic impact that strip mining has on ephemeral drainage basins, and the realization that the reclaimed surface configuration will only be an approximation of what once existed, a detailed premining channel study and analysis is of limited value. Of critical importance in the postmine landscape is the replacement of channel and sideslope features that compliment the undisturbed upgradient and downgradient channel and sidelsopes, and approved postmine land uses.

A primary goal of reclaiming drainage channels is to provide suitable habitats for aquatic and riparian vegetation, which are often found as linear features along drainage channels. Such habitat features are often associated with irregular drainage sideslope topography, and irregularities in the channels themselves. The creation of drainage area microsites promotes vegetation and habitat diversity, the importance of which is often overlooked during channel design processes, and during the physical work of reclamation. Although premine diversity is often noted in baseline data, described in permit application narratives, and labeled on maps as Drainage Bottom Types, Riparian Types, and 'Herbaceous Bottom, with additional subtypes labeled as overflow, subirrigated, marsh, wetland, and subirrigated,' appropriate consideration of the need to recreate such niches is often overlooked. It is important that ephemeral drainage channel designs provide for microhabitat features for vegetation, and that these features be replaced in the postmining landscape.

In consort with other Montana coal mine reclamation requirements, revegetation plans are directed towards reestablishing diverse, effective and permanent vegetation of the same seasonal variety and utility as vegetation native to the land to be disturbed. Properly constructed channels and sideslopes help fulfill this goal by creating a landscape that promotes vegetation community types such as grassland, conifer woodland, wooded drainage, and riparian/aquatic. The problem with rigorously engineered channels is that while they may be functional in terms of transporting water, they do not contain the ecological properties of native channels (Anderson, 1994). Designs are complicated by the reality of inherent channel instability, large fluctuations in discharge and a complex ecology (Shields et al., 1995a). Yet, if channels are appropriately designed and revegetated with riparian species, artificial erosion and sediment control measures should not be necessary (Stiller et. al., 1980). Therefore, efforts made towards natural channel restoration can produce immediate benefits for mine operators.

COMMON PROBLEMS

Reconstructed channels and sideslopes may not always closely resemble premine dimensions, and designs generally cannot take into account all hydraulic influences on these reclaimed features. What was once an undisturbed watershed has been backfilled with unconsolidated material, usually to a depth of one hundred feet or more, spoil graded, topsoil laid down, the area seeded, and perhaps shrubs and trees planted. After the upstream drainage channel is reconstructed, or perhaps reconnected with undisturbed portions of the basin, runoff is once again allowed to flow across the landscape. Runoff at this time, and until a stabilizing vegetative cover has been established, initiates the fluvial processes of erosion and deposition. It often takes three or more years for vegetative cover to become established on reclaimed sites, and, according to Martin (Martin et. al., 1988) it may take six years for infiltration and runoff to return to normal.

Constructed drainage channels are usually overly wide and simplified in comparison to what once existed, since channels are often located along former haulroads, often due, at least in part, to perceived or real equipment constraints. All too frequently, channels are reclaimed as straight, broad swales, even though they may be replacement features for coulees or small, incised channels that frequently exhibit considerable sinuosity. This is contrary to the fact that when most naturally occurring streams are viewed in cross-section they are not parabolic or semicircular in shape. Most natural stream channels are generally trapezoidal in straight reaches and asymmetric at curves and bends (Leopold, 1994). The construction of broad swales results in the creation of ecologically limited sites when compared to the diversity found in sinuous, irregular shaped channels (Shields et. al., 1995b). Although broad swales may achieve a suitable level of stability once vegetation becomes established, the initial lack of vegetative cover, and absence of meanders, often results in severe erosion, the formation of braided channels, and significant maintenance efforts during the first few years. Along with the problem of erosion, is the limited ability to achieve appropriate and diverse revegetation and wildlife habitat, when features such as coulees and small, incised channels are replaced with broad swales. The loss of microhabitat results in the loss of plant and animal diversity and in limited ecologic function.

SUGGESTED PRACTICES

Material can be placed in the overly wide channels to reduce channel width, thereby obtaining the appropriate width to depth ratio in reclaimed channels. Such features, as point bars or meander points, act as energy dissipaters and help to establish a meandering channel pattern. Narrowing drainage channel width does not necessarily infringe upon the required discharge capacity of the channel; rather it creates the proper channel width for a limited flow length. As noted by McIntosh (1989); Minor flows which contacted a bar eventually made an adjustment from relatively straight to sinuous as low flow water was guided around the tip of each bar. Major floods coursed over the bars. Thus the bars, rather than bed slope inconsistencies, dictated low-flow channel shape, and a return to premine sinuosity resulted. Delimited channel downcutting results from deflecting flows along the stream course, thereby allowing lateral erosional processes to enhance sinuosity. The end point of the lateral process is a meandering channel pattern (Hupp and Simon, 1991). When drainage channels and floodplains are reclaimed to an appropriate width and configuration during rough regrading, additional soil or overburden material, or engineered structures, may not need to be placed in the channel to form meander points. As indicated by Leopold and Wolman (1960), "The most characteristic features of all stream channels, regardless of size, are the absence of long straight reaches and the presence of frequent sinuous reversals of curvature."

Without meander points, or some other appropriate means of delimiting and deflecting stream energy, reconstructed channels tend to downcut, or to braid extensively, potentially leading to excessive instability, erosion and gullying. While other acceptable methods of delimiting and deflecting stream energy and creating suitable reclaimed channel sinuosity are available, establishing meander points in reclaimed drainage channels has proven to be beneficial at some Montana coal mines. With appropriate meander points in place, events greater than bankfull discharge are forced to flow over these low features, dissipating energy. These structures should be angled so that the downstream face is perpendicular to the desired direction of flow. This will direct the flow of water towards the center of the channel, away from the embankment, thereby further reducing the potential for erosion (Reichmuth, 1991). The spacing between meander points can be based on the relationship between meander length and bankfull channel width (Leopold and Wolman, 1960), the relationship between meander length and bankfull discharge (ASCE, 1997), or through the use of pertinent aerial photographs. Bankfull discharge is often approximated by the two-year annual peak flow event (Lowham and Smith, 1993).

The spacing of meander points in reclaimed drainages is intended to provide a semblance of a naturally occurring meander pattern. It is not expected that this reconstructed pattern will be a "perfect fit" within the hydraulically influenced landscape, or that localized erosion and aggradation will not continue to occur, especially during the first few years after reclamation. However, when properly placed, meander points can direct channel formation to an appropriate and acceptable level of relative stability and functionality in a reasonable timeframe. Without meander points, reclaimed channels often degrade into discontinuous and parallel gullies, with associated and unacceptable levels of erosion, possibly requiring years of maintenance work along with the accompanying delay in achieving postmining land use goals and bond release.

The use of meander points is a somewhat limited approach to proper drainage channel reclamation and does not compensate for improperly constructed flood-prone areas or sideslope features. If reconstructed channels, flood-prone areas, sideslopes and side tributaries were to more closely resemble what existed premining, the ability to achieve many reclamation goals and requirements would be further enhanced.

Meander points can provide a niche for planting trees and shrubs, e.g., stilling pools form at the junction of the placed material and embankment resulting in the deposition of sediment; some enhanced or variable moisture gradients can result at such sites, and; in general, microsites are created that allow for the establishment and survival of diverse vegetation. When trees, shrubs, forbs and grasses that my require such niches become established, they contribute towards a sustainable level of channel stability, and can enhance the ability of reclaimed landscapes to achieve overall revegetation and reclamation goals and standards.

The creation of features such as snow catchments, which collect and retain moisture, as well as areas wherein wildlife can take shelter from sun, wind and observation, also needs to be considered during channel reconstruction. As noted by Brookes (1995), "…improvement in ecological integrity will follow re-creation of physical characteristics."

There are a number of ways to estimate what the reclaimed channel width and depth and meander patterns should be; including taking actual predisturbance measurements in channels prior to disturbance, and the use of regional regression equations to provide an estimate of channel dimensions. However, since reclamation is to take place after strip mining, the proposed postmine topography needs to be considered in channel design. There may be significant differences between the premine and postmine landscape for a particular watershed, especially for the smaller basins. For such watersheds there may be relatively large gains or losses in drainage area, an overall change in the drainage channel slope, as well as in the length of flow from the drainage divide to the watershed outlet. Therefore, methods for designing channels may need to incorporate computer modeling to predict what the bankfull flow will be in the altered watershed, based on the reclaimed postmining topography.

The use of bankfull flow data for designing channel dimensions and form is preferable to most other methods, as this value is the end product of a multiple of factors (drainage area, slope, flow length, soil type, vegetation, etc.,). Generic designs could be created and categorized by various ranges of bankfull flow. Using predicted bankfull flow to design channels has to date resulted in reconstructed drainage channels that quickly achieved overall stability and functional use, while allowing on-going channel shaping geomorphic processes to proceed. Final channel shape will be influenced by initiation of erosional processes preceding the development of a stable and permanent vegetative cover.

CONCLUSION

If sufficient evaluation of relevant hydrological and ecological data and appropriate science and engineering is applied to channel design, the likelihood of returning reclaimed drainages to an acceptable and appropriate level of stability and functionality is enhanced. It is very important that reclaimed channels, and surrounding landscapes, are properly regraded, and in particular that drainages have a concave longitudinal profile with appropriately restored channel sinuosity. If regrading has left knickpoints, if an appropriate meandering pattern has not been incorporated into the channel design, if the vegetation does not `take, or a large storm event occurs during the early stages of revegetation, fluvial processes will likely cause severe erosion, requiring significant and repeated maintenance work. As noted by Stiller et al. (1980), successful reclamation depends on planning, and integration of the reclaimed surface and drainage network into the surrounding landscape.

Derivation and application of some generic or categorical channel design criteria may be relevant and useful in reclamation. Such designs could be derived that would adequately represent the majority of drainage channels that are to be reclaimed. However, there will always be instances when such generic designs are not adequate for achieving prescribed goals and functions. For example, case and site specific design criteria will likely be necessitated when drainages are to be reconstructed in steep landscapes, or when special ecological requirements must be met. In other cases, designs may not be needed at all, such as for small watersheds, or for the upper reaches of a watershed. In such instances, it may be appropriate to construct swales, or allow for short reaches of steep-sided and comparatively erosive channels.

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