A COMBINATION OF TECHNIQUES FOR RECONSTRUCTION OF EPHEMERAL STREAM CHANNELS IN WYOMING[1]

by

Steve McIntosh[2]

Abstract. A combination of Manning's and geomorphic designs provides a channel construction method which satisfies the full set of requirements for bond release that neither design alone can guarantee. The essence of bond release requirements is a stable valley containing a meandering low-flow channel. Manning's design provides the best assurance of a stable valley. Theoretically a sinuous channel will form within Manning's valley. However unavoidable slope variations in the valley floor will delay or prevent evolution of the meandering channel. To assure formation of a sinuous channel within the 10 year bond period, geomorphic design methods can be used. Premine geomorphic inspections are studied in order to determine the slope and shape of the channel which reclamation authorities consider ideal. This prototype course is superimposed onto the floor of a Manning's valley. Alternating wedge-shaped bars are then installed in the valley to guide low flows along the desired sinuous course. Bars are constructed at a height which does not interfere with valley floods. Using this approach, regulatory mandates for hydrologic reclamation are satisfied assuring achievement of the ultimate industry goal of bond release.

Additional Key Words: geomorphic sizing techniques, meander bars, alternate bar spacing, quasi-equilibrium.

Introduction

Unless stream-channel reclamation methods can begin to address regulatory requirements, mining companies stand to lose a significant amount of bond capital. Too much erosion has occurred on sites where conventional stream-sizing techniques have been used. A new channel reconstruction program is demanded. Manning's design formula has proven the most workable reconstruction format in the past. However, the design has not proven capable of providing answers to all the requirements made of reclaimed channels.

In the mining industry, the success of any reclamation design is measured in terms of its ability to insure permit approval and guarantee a return of bond monies. Manning's model has provided both positive and negative aspects to our reclamation program. Positive features include inexpensive construction, proof of flood capabilities, and channel width measurements which are ideal for formation of a sinuous channel. Negative aspects are an inability to control erosive flows and a lack of visual appeal. The positive elements of

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Manning's equation meet the first objective of a reclamation program by providing assurance of permit approval. The negative aspects can result in a failure to achieve the second goal of bond release. The positive elements of Manning's must not be sacrificed in the formulation of a new design approach.

Goals and Constraints

Mine land reclamation in Wyoming is regulated by the Wyoming State Department of Environmental Quality (DEQ). This agency sets standards for permitting and bond release. As suggested by the DEQ, native materials should be used in the construction of permanent drainages. The reclaimed channels must look and act like the premine courses. The reconstructed channels must also have the theoretical ability to withstand the 100-year, 6-hour flood event. Industry goals are simply to attain permission to mine and to achieve bond release at the minimum possible cost.

Financially, the mining industry considers the ideal reclamation program one which does not require a slowdown or interruption of the processes necessary for ore removal. In this scenario, backfilling and topsoiling are the unavoidable phases of mining during which the ideal reclamation program would take place. In the bentonite-mine region of northeastern Wyoming the smallest piece of construction equipment is a scraper with a 31 cubic yard capacity. At Baroid this means that, during maximum production, each drainage will be constructed by a fleet of scrapers moving soil and spoil at the rate of approximately 70,000 cubic yards of material per hour.

Channel restoration and elaborate engineering designs provide the ideal answer to permit requirements, yet neither approach is feasible. Restoration of any drastically disturbed area has long been recognized as impossible. Both restoration and complex mathematical models require fabrication of myriad channel details. Construction equipment is too large and time is too limited to allow institution of the detail demanded by these approaches.

Though complex engineering design formulas have proven impractical, the information required by Manning's equation is relatively easy to supply, and the resulting blueprints low-cost and simple to implement. Industry demands are met because of operational feasibility. However the unmodified design fails to address the entire set of regulatory goals established for full bond release. Manning's channels provide proof of flood capabilities but, as constructed, they are not appropriate in appearance. The designed flood courses are normally straight, flat-bottomed chutes. Frequently, the meandering channel desired by regulators will not evolve within a Manning's channel within the 10-year bond period.

Discussion

Manning's Equation

Manning's equation (1) defines the maximum permissible flow velocity in terms of channel design parameters:

$$Vp = 1.49/n \times R^{2/3} \times S^{1/2} \qquad (1)$$

where:

Vp = Maximum Permissible Velocity
R = Hydraulic Radius
S = Water Surface Slope
n = Manning's Roughness Coefficient

The premise of Manning's equation is that, if all other factors are held constant, erosion will be decreased if channels are made wide and shallow. Manning's channels are normally trapezoidal in cross section with side slopes at a maximum of about 3h:1v (Figure 1).

Per regulatory requirements, channels are sized for the 100-year, 6-hour event (WDEQ 1980, 1986). Detailed knowledge of the disturbed soil and spoil is not necessarily demanded by Manning's equation. No attempt need be made to accurately characterize the final material used to construct the channel. Rather, the most erosive mixture of soil and overburden which can result from mining is used in Manning's equation. Dimensions calculated using this hypothetical "worst case" material describe the channel most often considered the safest and the most acceptable flood course by regulatory authorities. Consequently, wide Manning's channels are central to the topic program.

Channels designed according to DEQ guidelines are equal in width to the native flood plain. Because of the similarity in appearance, the dimensions for Manning's 100-year, 6-hour course will be termed a valley or flood plain. The wide, shallow course calculated for the 100-year event is consistent with the reasoning behind Manning's sizing technique. Theoretically, the dimensions are meant to describe a course which will allow a meandering channel to develop because it is so wide. And in most cases Manning's valley will promote formation of a sinuous channel. But frequently the time needed for establishment of a meandering channel is too great. A sinuous channel often fails to develop within the ten year bond period. This is largely attributable to irregularities in the bed of the rebuilt valley.

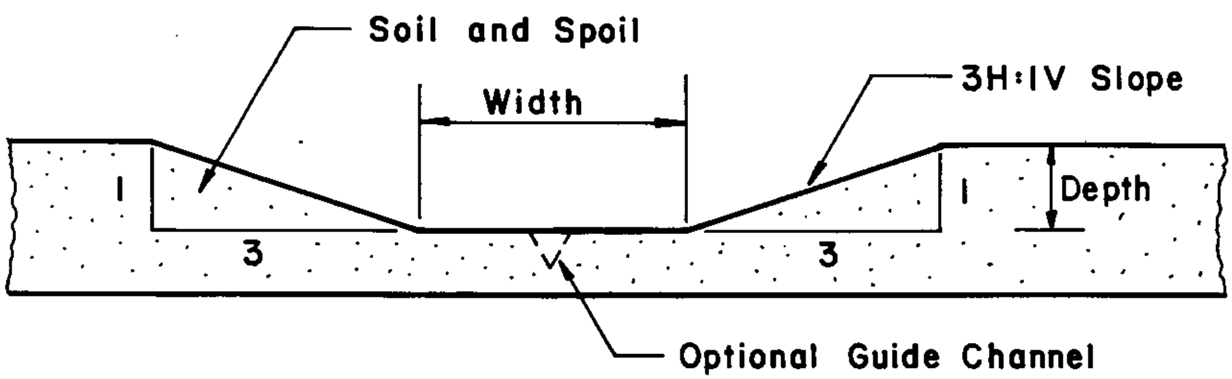

Figure 1. Trapezoidal cross-section of typical Manning's channel. Optional V-ditch guide channel in center of channel.

<u>Design Problems.</u> The most significant shortcoming to Manning's design is the inability of the constructed channels to compensate for slope inconsistencies. Consequently, an unacceptable amount of erosion can occur. The obvious solution is to build uniform channel surfaces. However experience has shown that grade variability is an unavoidable consequence of construction.

When maximum quantities of soil and overburden are being moved, mine equipment is incapable of cutting a consistent channel slope. Lowering the rate of material movement in order to improve channel construction raises production costs while doing little to smooth bed slope inconsistencies.

Inevitably, the final channel floor contains many ridges, furrows and holes which are not part of the initial blueprints. The settling of soil and spoil after placement exacerbates slope variability. Thus unplanned slumps and ridges, not Manning's design slope, often prove to be the major determinant of channel direction. Frequently the pattern and direction of this altered flow is unacceptably erosive.

Several attempts have been made to modify Manning's channels in an effort to produce more natural looking, non-erosive channels. One approach involves cutting the desired low-flow course in the bed of the rebuilt flood plain. These guide channels are commonly narrow V-shaped ditches (Figure 1). Without exception, narrow guide channels have proven to be excessively erosive. A positive aspect of Manning's design is being compromised. in an attempt to remedy a negative component. The V-ditch, which is built in order to improve appearance, promotes gullying rather than introducing sinuosity. Low-flow water is denied access to the valley width that is so crucial to the effectiveness of Manning's design. Additionally, the unmodified channels remain unequipped to control erosive flows. Quick adjustment to a sinuous course must be guaranteed. Because bed-slope inconsistencies are unavoidable, grade-control features must be constructed within the Manning's valley.

Geomorphic Design Approach

According to regulatory guidelines, permanent channel features must be made with native materials. Erosion control features built with soil and/or overburden will meet the legal requirements for building materials and can be installed using the mine equipment available. Properly designed, soil bars can be built without compromising peak mine production. However soil bars used in the area in the past have proven unsuccessful as erosion control devices.

The failure of past soil bars can be blamed on two basic design mistakes: (1) placement of bars within improperly designed valleys and (2) construction of inappropriate bar dimensions. In the past, bars were not designed as part of a comprehensive plan. They were installed in order to change channel direction in a valley system which was unstable at the time of construction. The soil bars presented in this discussion are meant to assure sinuosity in a valley designed for the model channel. The proposed bars are placed in a valley in order to reinforce Manning's design theory.

Meander bars have proven to be an asset only in a stable valley system. Soil bars do not have the structural strength necessary to stabilize a valley which is too narrow or too steep in relation to the volume of water it conveys. Nor can soil bars successfully convert a valley from convex to concave-up (looking upstream), a profile that is considered to be stable. The proper profile shape and slope must be insured in the valley design. Geomorphic relationships can be studied to determine the ideal valley configuration.

Manning's design provides suitable one-dimensional blueprints (plan view and cross section) for valley width and depth. But the design does not describe a stable valley. Stability can only be approached if a concave-up valley profile is part of the construction plan. The slope of the profile is dictated by the zone of disturbance. The gradient of the reclaimed valley must be intermediate between the unaffected reaches above and below the zone of disturbance (Bergstrom 1985). Premine valley sinuosity should be copied. The more closely the sinuosity of the constructed flood plain approaches the premine shape, the more guarantee there is that the rebuilt valley will have a concave-up slope which approximates the premine slope.

Channel. Manning's flood valley will contain the channel. The reclaimed channel slope and shape is most appropriately based upon ideal premine channel reaches (Bergstrom 1985). Since bond release is the ultimate objective of this reclamation program, channel appearance should be based on what the reviewing agency considers ideal. Bond release reviews conducted by the DEQ have revealed the channel form which is considered the standard for bond release.

Third-order stream reaches are commonly deemed stable in those sections where sediment flow exiting the area slightly exceeds that which enters. According to this definition, a slight amount of sediment loss is considered the condition of quasi-equilibrium. In appearance, these areas are characterized by well-grassed channel slopes where the low-flow channel is wider than it is deep. Meander bars are alternately spaced in a regular repeating pattern.

Bar dimensions. The second major reason for the failure of past channel bars is improper bar shape. The length, angle, slope and height of soil bars have not historically been considered important dimensions. Meander bars were installed in order to create a sinuous low-flow channel. If bars were built too tall it was not considered harmful. The common feeling was that the higher the bar, the better it would function. But the three-dimensional shape of the bars has proven as critical as position to the stability of the reclaimed hydrologic system.

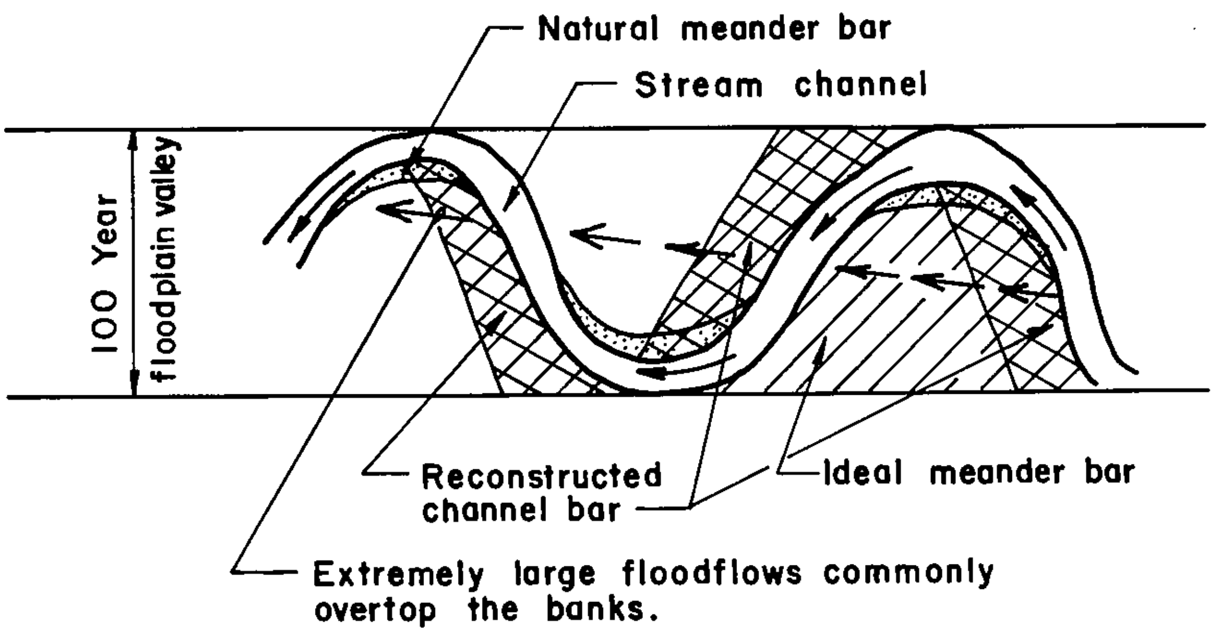

Figure 2. Plan view of ideal stream section. Upstream edge of ideal meander bar is the blueprint for the reconstructed channel bars.

In order to determine channel bar spacing, length and plan-view angle, the ideal premine channel reach is superimposed onto the floor of the valley (Figure 2). This model section is repeated the length of the valley. Irregular channel features which are common in the natural channel are not duplicated. The upstream edge of the ideal meander bar will serve as the blueprint for the proposed channel bars. The origin of each bar is the 100-year valley bank while the distal point represents the inside edge of the 10-year flood channel.

The vertical dimensions of the soil bars are crucial to the stability of the reclaimed stream system. Channel bars are features of the larger valley system and represent an obstruction to major water flows within the Manning's valley. If they are physical barriers, bars can deflect flood flows causing too much erosion on valley walls and on the bars themselves. To maintain state-approved flood capabilities, bars must be shaped in order to account for flood events. The width, depth and direction calculated for each major event must be reflected in the channel bar design.

Flood flows take a more direct route downstream than low flows (Lowham 1987). As flood volume increases (flood event increases), the more direct the route becomes (Figure 3). As theorized here, all events greater than the 10-year flood event will take a more direct down-valley route than is described by the low-flow channel. The smallest flood (10 year) will thus have a slightly sinuous route while the maximum flow (100-year) will take a "straight-line" down-valley route. This means that flood waters will tend to flow over the constructed meander bars. In terms of design, it is essential that flows greater than the 10-year event be allowed to flow freely over each bar.

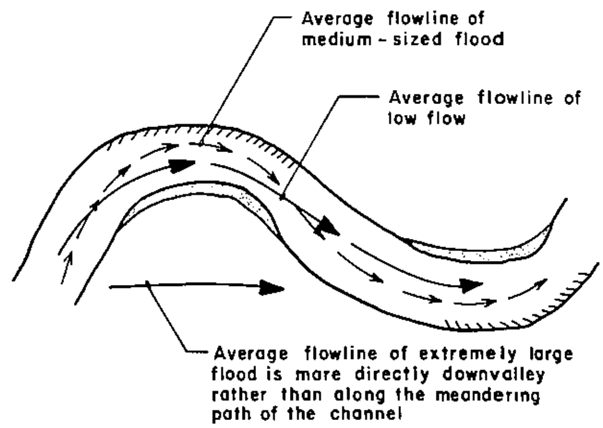

Figure 3. Average direction of flow of stream at various discharges. For a meandering channel, the average flowline straightens with increasing discharge. (After Lowham 1987).

Study Area

The study area is located on the Redbird 9 mine property in the extreme southeastern corner of Montana, approximately 8.8 miles west of Alzada, Montana. The disturbed channel is an unnamed third-order drainage. The headwater area is steeply dissected, with a maximum elevation of about 3,640 feet and an elevation at the lower end of the disturbance of about 3,530 feet. The mean slope of the premine valley is 3.0 percent. The slope of the low-flow channel averages 1.2 percent. The area of the watershed is about 96 acres.

Topsoil material is highly swelling montmorillonitic clay loam while subsoils are massive, montmorillonitic clays. Spoil material consists of fine, soft marine shales. Both spoil and soil are very saline and extremely sodic which leads to exaggerated subsidence. The high degree of sealing and swelling which characterize these soils results in extremely low permeability and slow water infiltration. Consequently, runoff is very high. The area is largely barren, with drought-tolerant wheat grasses dominating.

Construction of Redbird 9

The Redbird 9 drainage is one of three stream courses built using the outlined construction approach. Construction of the Redbird 9 drainage began in the winter of 1987. Valley width was determined by comparing Manning's 100-year flood plain with the unaffected valley width. For operational purposes the larger of the two widths was used for construction of the valley. By using the greatest valley width, a larger area is available for natural channel adjustments. The large area also facilitates equipment movement should any future reparation work be needed.

The width of the reclaimed valley floor is 80 feet. The channel bars were designed 50 feet long and 20 feet wide. The 10-year flood channel is 30 feet in width. The inside bar angle is about 63 degrees. Each bar is sloped from a height of about 2 feet on the valley wall to 0.3 feet at its distal point. The allowed channel gradient is 1.3 percent. Approximately 40 cubic yards of soil and overburden were used for each bar. This small amount of material was dumped on the valley floor while peak soil movement was maintained. Construction was therefore very inexpensive.

Manning's design was used to determine valley depth and the vertical dimensions of channel bars. Sizes were derived for all flood events from p10 to p100 (valley). The flood courses were then stacked. Stacking is analogous to fitting progressively smaller trays into slightly larger containers. The p10 event is on the valley floor and the largest event (P100) is on top. The outside edge described by this hypothetical stacking represents the design slope of each bar (Figure 4). The final height of the stacked flood

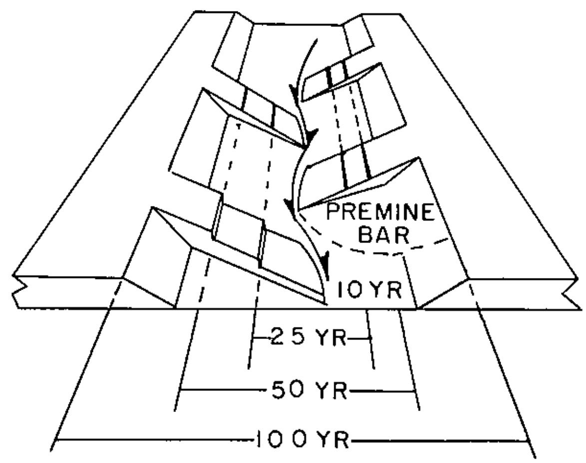

Figure 4. Oblique upstream view of reclaimed valley showing flood event capabilities.

channels determined the minimum total valley depth. About one foot of freeboard was added to this height. The bank slopes of the valley are arbitrarily set at a maximum of 3h:1v and a minimum of 5h:1v. These slope percentages appear to be the compromise best suited to allow seeding and provide channel stability. Table 1 summarizes the method used to calculate each hydrologic feature for the Redbird 9 drainage.

Results

The reconstructed Redbird 9 valley now contains a hydrologic system which resembles the premine state in dimensions and appearance. The reconstructed valley has a concave profile with a slope of about 3 percent. The low-flow channel which has formed on the valley floor has a sinuous course with an average slope of about 1.3 percent. Cross-sectional areas of premine and reclaimed low-flow channels also emphasize channel-measure similarities. The reclaimed low-flow

Table 1. Sizing method used for each valley and channel dimension.

	Valley	Channel
Slope	Geomorphic	Geomorphic
Plan View Shape	Geomorphic	Geomorphic
Width	Largest of Geomorphic & Manning's 100-yr. event	Manning's 10-yr. event
Depth	Sum of Manning's 10-100-yr. events	Low-flow channel=free-form*
Features	Side slopes 3:1 max. and 5:1 min.	Alternate Bars: Dimensions: Geomorphic Height/Slope: Manning's
Construction	Cut after overfilling	Dump bar material on valley floor

*'Free-form' implies that unimpeded water flow within the valley is allowed to form the low-flow channel (Lidstone 1982).

channel area (which evolved free-form) averages 2.0 square feet, wheras premine channel area was about 1.8 square feet.

Numerous small runoff events and three bank-full flows have occurred since completion of the drain course. The first major flood occurred two months after construction. Floods were estimated to range between the 5- and 10-year events. During each flood, the ground was frozen or saturated to an estimated depth of six inches. All water flow within the valley occurred before any vegetation was established. The amount of runoff and the susceptibility of the drainage to sediment loss was thus exaggerated (Heede 1974).

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.

The bars interrupted potentially erosive courses in two places. The formation of one gully was due to slope variability caused by equipment limitations. The evolution of the second gully was dictated by snow drifts. Two small ponds formed on the upstream side of the channel bars at these locations. Sediment from subsequent channel flows has completely filled these ponds. System adjustment has occurred to the point of quasi-equilibrium within the valley.

Conclusions

The valid aspects of geomorphic and Manning's channel-sizing theories can be combined in a construction program that is superior to programs designed on the basis of either theory alone. The cornerstone of this approach is a wide valley floor with a concave-up profile. The valley slope should be intermediate between the areas above and below the disturbance. Premine valley sinuosity should be copied from the undisturbed area. This provides assurance that the premine slope gradient and shape will be returned to the reclaimed area.

In design planning, the ideal native channel is superimposed onto the valley floor. Using the sinuosity of this ideal channel reach as the template, soil bars can be installed which counteract valley-slope inconsistencies and assure formation of a stable meandering channel. By constructing each channel bar at a height which compensates for major flood flows, regulatory demands are satisfied; the flaws that can result from using Manning's equation alone are mitigated. Major floods are allowed to flow unencumbered within the valley. Sinuosity is introduced without compromising long-term stability. The end result is a channel which has a concave-up profile with a slope less than the containing valley. Since this slope relationship existed in the premine area, long term stability is assured. The small amount of material needed for each bar made this approach very cost effective. A self-adjusting channel has quickly evolved which satisfies the full set of regulatory and industrial demands. With the assurance of bond release, the ultimate goal of reclamation is achieved.

Literature Cited

Bergstrom, F.W., 1985. Determination of longitudinal profile for stream channel reclamation. p. 29-60. In Second hydrology symposium on surface coal mines in the Northern Great Plains: Proceedings of the workshop. Gillette Area Groundwater Monitoring Organization, Colorado Ground-Water Association and Wyoming Water Research Center.

Heede, B.H., 1974. Stages of development of gullies in Western United States of America. Ziet. Fur. Geomorph. (18): 260-271.

Lidstone, C.D., 1982. Stream channel reconstruction and drainage basin stability. p. 43-58. In Hydrology symposium on surface coal mines in the Powder River Basin of Wyoming: Proceedings of the workshop. (Gillette, Wyo.). Gillette Area Groundwater Monitoring Organization and American Institute of Mining Engineers.

Lowham, H.W., 1987. Fluvial processes and design. Excerpts from U.S. Geological Survey Water Resources Investigation Reports 86-4329 and 81-71. 47 p. Wyoming Department of Environmental Quality, Cheyenne, Wyoming.

Wyoming Department of Environmental Quality, 1980. Guideline No. 8, Hydrology. 22 p. Land Quality Division.

Wyoming Department of Environmental Quality, 1986. Rules and Regulations. 230 p. Land Quality Division.