WATERSHED RECONSTRUCTION DURING THE REHABILITATION OF SURFACE MINED DISTURBANCES[1]

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and

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Abstract.--The focus of this study was to develop a step-by step procedure to design reconstructed watersheds. A preliminary procedure was developed through a literature review and tested through a case study. The preliminary procedure was then revised to accommodate the findings. The results show that the reconstructed watersheds closely resemble the pre-mined drainage composition if the design procedure is followed. It is hoped that such a design will decrease the time it takes post mined watersheds to reach their dynamic equilibrium and thus, reduce erosion.

INTRODUCTION

Water pollution caused by erosion is a major concern of any surface mining operation. Past research on the reduction of sediment during rehabilitation has concentrated on methods used to help establish vegetation, thus, reducing erosion. Recently however, more attention has been placed on reconstructing a watershed which is in dynamic equilibrium with the pre-mined site conditions. It is thought that erosion could be reduced if the post-mined watershed is designed to include the pre-mined drainage characteristics.

This study examined the problems associated with designing reconstructed watersheds during the rehabilitation of surface mined-land. The basic objective of the study was to develop a step-by-step procedure to be used in designing a reconstructed watershed.

METHODOLOGY

A preliminary procedure was developed using three studies as a guide. Those studies were, 'Sculpturing Land to Decrease Erosion" by Schaefer, Elifrits, and Barr (1979), the "Geohydrologic Regime of the Powder River Basin" by Divis and Tarquin (1981), and "Commentary on Guidelines No. 8 and No. 9 by Divis (1981).

A case study then was used to analyze the preliminary procedure. The Powder River Basin in Wyoming was chosen as the case study area. This decision was based on the large amount of surface coal mining in the area. The Belle Ayr Mine, owned by AMAX Coal Company was chosen as the case study site. It was chosen primarily because AMAX Coal Company was willing to provide the base data necessary for the study.

The preliminary design procedure was then analyzed. The analysis focused on problems encountered during each step of the process. The procedure was then adjusted to accommodate or avoid the problems encountered.

PRELIMINARY PROCEDURE DEVELOPMENT

The three studies named earlier were used as a guide for the preliminary procedure development.

Schaefer, Elifrits, and Barr (1979) examined erosion on rehabilitated sites in Missouri. They concluded that if a watershed in dynamic equilibrium with the surrounding landscape were placed on the rehabilitated site, erosion could be reduced.

One approach to approximate the terrain of a watershed in dynamic equilibrium was to estimate the average area of the zero order watershed from the pre-mined topography. The zero order watershed

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is the area of overland flow in which the runoff produced initiates channel development. Graphically, zero order watersheds are described in figure 1. The researchers found that the area

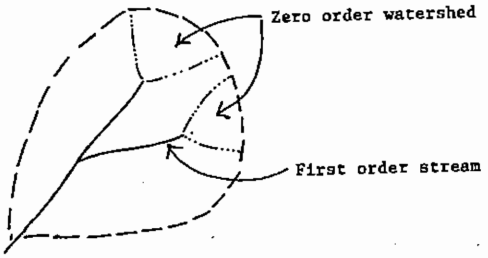


Figure 1.--Zero order watersheds.

of the zero order watershed is a function of the erosional process.

Divis and Tarquin (1981) examined stable watersheds in the Powder River Basin in Wyoming to determine how rehabilitation efforts could be enhanced to reduce the time of obtaining a new dynamic equilibrium.

They concluded that a numerical regime equation best described stable watersheds. The first order drainage basin was considered an important parameter in reconstructing the drainage system. This is because the first order basins supply the majority of runoff and sediment loading within the system.

The third study, Divis (1981) suggested a design procedure to be used in reconstructing watersheds. The procedure basically establishes the macrotopography of the rehabilitated site and then delineates the major tributary basins and their streams. Finally the lower order channels are designed and the amount of expected erosion is estimated.

An additional paper by R.E. Horton (1945) described erosional development of streams and their drainage basins. A Horton Analysis of a watershed indicates its degree of stability. One quantitative measurement in a Horton Analysis, important in designing reconstructed watersheds, is the drainage density (D_d). Drainage density describes the degree of drainage development by determining the total stream length within the watershed and dividing by the basin area. Numerically it is expressed:

$$D_d = \frac{\Sigma L}{A}$$

L = Length of Stream, in miles
A = Area of Basin, in square miles

The preliminary procedure was developed based upon the findings and the parameters described earlier. The area of the zero order watershed was used as the design base. According to Horton (1945), streams will erode up a valley if the amount of overland flow exceeds its critical length. The "critical length" is described as the distance from the ridge to where the erosive forces exceed the resistive forces. Thus, it is the amount of overland flow which is critical to the design of the reconstructed Watershed. The size of the zero order watershed is a function of the overland flow and an accurate indicator of channel development. Figure 2 graphically shows the delineation of the zero order watershed using the critical length of overland flow as the basis.

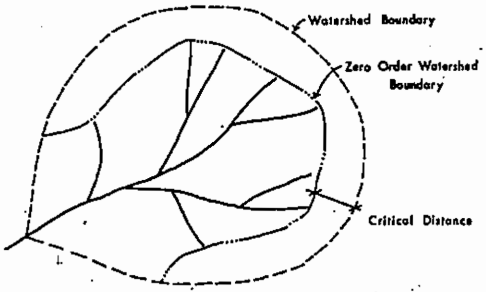


Figure 2.--Zero order watersheds based in the critical length of overland flow.

PRELIMINARY DESIGN PROCEDURE

The first step of the preliminary design procedure was to determine the appropriate scale for the base topographic maps and aerial photography of the pre-mined landscape. The optimal scale shows the initial channelization of the overland flow. The base information provided by AMAX was at a scale of 1" = 500' with a contour interval of 5 feet. This information was used by AMAX in their mining permit application according to criteria set by the Wyoming Department of Environmental Quality (WDEQ). For this study, this scale allowed sufficient detail while not being too cumbersome. However, in areas outside the Powder River Basin, the appropriate scale could change.

The second step located all the streams on the site. It is necessary to locate all the streams within the site so stream orders can be determined. One problem encountered in locating streams was Caballo Creek which meandered through the site. Once the streams entered the Caballo Creek floodplain, they were virtually impossible to locate. However, all the streams could be located to the average amplitude line of the Caballo Creek meanders. Therefore, all the stream measurements ended at the average amplitude line of Caballo Creek.

In addition, it was important to locate all streams which flowed into and out of the site. This was necessary to find, so off-site drainages could be restored upon rehabilitation.

The third step was to locate three sample watersheds. A sample watershed was one in which all first order streams could be located and which had a minimum of a third order stream at its outflow. At the Belle Ayr Mine, there were ten such watersheds. In a couple of cases, it was necessary to extend off-site in order to locate all the first order streams.

Of the ten potential sample watersheds, three were chosen for data collection. Those potential sample watersheds with a large number of manmade structures were eliminated. Also, some sample watersheds were more heavily populated with streams than others. Of the three watersheds chosen, one was heavily populated, one was sparsely populated, and the third had an average population of streams. In this way, it was thought that the sample watersheds reflected the true nature of the pre-mined site.

The fourth step of the procedure was to delineate the zero order watersheds in each of the sample watersheds. A line was drawn connecting each first order stream (fig. 2). In some cases, a short first order stream existed between two long first order streams (fig. 3). Abnormalities such as this, were not included in the delineation of the zero order watershed. In addition, the zero order watershed boundary ended by determining the elevation of the last first order stream connected. The zero order watershed boundary continued along that elevation until the ridge was met.

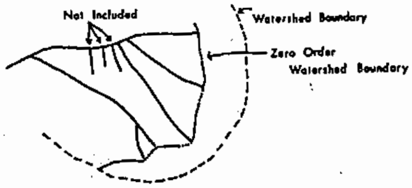


Figure 3.--First order streams not included in the zero order watershed area.

The average area of the zero order watershed was determined by dividing the total area by the number of streams which were created by the zero order watershed.

The fifth step measured the following within the sample watersheds for each stream: basin area, stream length, and stream slope.

Step six calculated the following within each sample watershed and between the three sample watersheds: average drainage density, average basin area, average stream length, and average stream slope.

Steps five and six gave an indication of the re-mined watershed characteristics and stability. his indicated the characteristics of the recontructed watershed.

In step seven, additional data was collected rom written sources. The data collected was: epth of overburden, depth of coal seam, mining nd rehabilitation methods, and soil and overburden characteristics. One important reason behind this data collection was to determine the relative change in elevation during rehabilitation. In the Powder River Basin, the relative elevation can drop from 20 to 100 feet. Elsewhere in Wyoming, there is a net gain in elevation.

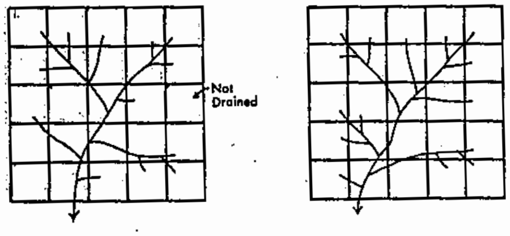
Although it was recognized that the change in elevation would greatly affect the hydrologic characteristics of the site, it was determined that considering such changes was beyond the scope of this study. To alleviate the problem, this study assumed there would be no drastic change in elevation.

The eighth step was to place a grid the size of the zero order watershed over the entire site. The basis behind this step was that the zero order watershed is the maximum amount of land exhibiting overland flow without creating a channel. Once that area is exceeded, a channel will form. Thus, if a grid the size of the average zero order watershed is placed over the site, each square created must be drained by a channel.

To determine the size of the grid, the square root of the average zero order watershed area in square feet was taken. The result was the length of one side of a square the size of the average zero order watershed. An overlay of the grid was placed on the site base map.

Step nine established the macrotopography by first locating all the streams which flowed into and out of the site. Then those streams were located in their approximate pre-mined locations. Once those streams were relocated, the remaining portions of the site were divided into the same number of sample watersheds that existed in the pre-mined landscape. High and low points for each smaller watershed were then located.

Step ten began to establish the streams on the rehabilitated landscape. The guidelines for placing streams were the following. Each square created by the grid must be drained by a channel. The channel can be of any order. For a square to be considered drained, a channel must begin, flow alongside, or flow through a square (fig. 4).



Incorrect

Correct

Figure 4.--Establishing streams on the rehabilitated site.

Each square must be drained for the site to be considered drained. Once a square has been drained, there is no need to place another channel in that square. One exception is when two channels join. When streams flow together, the angle created between the streams should be 90 degrees or less.

To begin designing the watershed, a single channel was drawn from the high point of the watershed to the low point, the point of out flow. Then starting at the high point again, the rest of the stream channels were drawn to the criteria stated earlier. Sometimes it was necessary to move the initial stream channel to create a more natural looking drainage network.

Step eleven established the topography. A concave profile of the largest stream was drawn using the new length and elevation of the reconstructed watershed. Creating a concave profile is important because that is the least erosive stream channel condition.

Once the profile was completed, the corresponding contours were drawn on the plan of the reconstructed watershed. The contour interval used in the case study was a 10 foot contour interval. This was primarily for ease in calculating and drafting. Further studies are needed to determine the affect volumetric expansion or a net loss in elevation has on the post-mined reconstructed landscape.

Step twelve once again measured the basin area, stream length, and stream slope, but on three reconstructed sample watersheds. The average basin area, average stream length, average stream slope, and drainage density were also calculated. From these measurements, a comparison of the pre-mined and post-mined reconstructed watersheds could be conducted.

Step thirteen compared the results. Table 1 is a summary of the pre-mined and the post-mined data.

The basin area and the stream lengths of the poat-mined landscape corresponded to the pre-mined landscape in the lower orders. Because the lower the order, the more streams, there is more data for the first and second orders than the others. It is felt that if the data set for the third, fourth and fifth orders was greater, they too would correspond. The averages for the pre-mined and post-mined zero order watersheds were extremely close. This indicated that the zero order watershed system accurately depicted the zero order watershed.

The drainage density for the post-mined landscape did not correspond to the pre-mined. Upon reinvestigation of the pre-mined drainage network, it was felt that the three sample watersheds chosen in the data collection were more highly populated than the average. It is anticipated that if the total drainage density were calculated for the site, the calculations would correspond.

Table 1.--Pre-mined and Post-mined reconstructed watershed summary data.

	Order	Pre-Mined	Post-Mined
Drainage Density (mi./sq.mi.)		23.00	14.00
Basin Area (ss.mi.)	0	.0035	.0034
	1st	.0052	.0054
	2nd	.0240	.0211
	3rd	.1365	.0808
	4th	.1887	.3285
	5th	.3429	.5661
Stream Length (mi.)	1st	.0685	.0640
	2nd	.1135	.1041
	3rd	.2443	.2088
	4th	.4356	.3725
	5th	.4261	.2581
Stream Slope (%)	1st	7.3	3.6
	2nd	4.7	3.0
	3rd	3.7	2.3
	4th	2.7	4.0
	5th	2.2	0.4

One change in the post-mined landscape that must be noted is the drainage pattern. The post-mined drainage pattern is dendritic and much more evenly spaced than the pre-mined. This is due to the zero order grid. Because stability of a watershed does not depend upon the drainage pattern, this should not matter. The hydrologic characteristics listed earlier are a more accurate indicator of the stability of a watershed.

The slope of the post-mined landscape was much lower than the pre-mined. This was because the post-mined stream profiles were much more concave than the pre-mined. For future studies, profiles taken of the pre-mined watersheds would help in the design of the reconstructed watershed. However, the slope is one characteristic which can easily be changed to reflect the pre-mined conditions.

The final step, fourteen, adjusted the post-mined watershed to more closely reflect the pre-mined drainage characteristics.

THE FINAL DESIGN PROCEDURE

The following is a synopsis of the final design procedure adjusted after analyzing the case study.

Step 1: Gather base information.
  a. Determine the appropriate scale of map.
  b. Obtain a topographic map and aerial photography at the appropriate scale.

Step 2: Locate all streams and determine their order
- a. Use a mylar overlay to draw the streams from the base information gathered in step 1.
- b. Locate where streams flow into and out of the site. Delineate their drainage basins on the site.

Step 3: Delineate the potential sample watersheds.
- a. Locate all the potential sample watersheds on the mylar overlay. All the first order streams must be located. The outflow of the watershed must be a third order stream.
- b. Delineate the sample watershed drainage basins and record the number of sample watersheds.
- c. Choose three sample watersheds for data collection.

Step 4: Delineate the drainage basins for each stream in the 3 sample watersheds.
- a. Place tracing paper over the sample watersheds to be measured.
- b. Color code the streams by order.
- c. Delineate the drainage basins for each stream using the same color code as its stream order.
- d. Number each stream within each order.

Step 5: Delineate the zero order watersheds.
- a. Draw a line connecting the beginning of each first order stream.
- b. Omit first order streams which will skew calculations.
- c. Determine the elevation of the last first order stream. Continue the zero order watershed at that elevation until the boundary of the sample watershed is met.

Step 6: Measure the following in the three sample watersheds.
- a. Basin area of each stream. Record by order.
- b. Stream length of each stream. Record by order.
- c. Change in elevation for each stream. Record by order.
- d. The zero order watershed area and the number of streams created by the zero order watershed.

Step 7: Calculate the following from the data collected in step 5.
- a. Average drainage density.
- b. Average basin area.
- c. Average stream length.
- d. Average stream slope.
- e. Average stream numbers.
- f. Interpret the data to see if the pre-mined sample watersheds correspond to a Horton Analysis. If not, collect more data on additional watersheds.

Step 8: Collect data from written sources
- a. Collect the following from data in the mining permit application: depth of overburden, depth of coal seam, mining methods, rehabilitation methods, and soil and overburden characteristics.
- b. Estimate the elevation of the rehabilitated surface.
- c. Estimate soil characteristics to determine the amount of potential erosion upon rehabilitation.

Step 9: Place a grid the size of the zero order watershed over the entire site.
- a. Determine the dimensions of a square equal in size to the average area of a zero order watershed.
- b. On another mylar overlay, place a grid over the site with the dimensions determined earlier.

Step 10: Establish new sample watersheds.
- a. Establish the entry points of all streams which flow into or out of the site.
- b. Locate those streams to their approximate original locations and size.
- c. Divide the remainder of the site into the same number of sample watersheds that existed in the pre-mined topography.

Step 11: Establish the relative topography of the post-mined site.
- a. Determine the elevation of streams which flow into and out of the site.
- b. Determine the relative elevation of the adjacent landscape.
- c. Locate the high and low points of each new sample watershed.

Step 12: Establish the stream channels within the sample watersheds.
- a. Draw a single channel from the high point to the low point in the new sample watersheds.
- b. Draw the remaining channels to the following criteria: Each square created by the grid must be drained by a channel. The channel can be of any order. For a square to be considered drained, a channel must begin, flow alongside, or flow through a square. Each square must be drained in order for the site to be designed properly. Once a square has been drained, there is no need to place another channel in that square. The angle created between the streams should be 90 degrees or less.

Step 13: Establish the topography.
  a. Draw a concave profile of the longest stream in the watershed.
  b. Locate the contour lines at a 10 foot contour interval.
  c. Transfer the location of the contours on the plan.
  d. Repeat the step for other long streams within the watershed if necessary.
  e. Connect the points of equal elevation creating the contour lines.

Step 14: Locate three sample watersheds on the reconstructed site.
  a. Choose three new sample watersheds on which data will be collected.
  b. Repeat step 4 for each new sample watershed.

Step 15: Repeat steps 6 and 7 for each of the new sample watersheds.

Step 16: Compare the pre-mined data with the designed post-mined data.
  a. Compare the two analyses. If the two data sets are not similar, return to step 12 and redesign the watershed.

FUTURE STUDIES

Because the design of reconstructed watersheds is a new area in the field of mining rehabilitation, much additional research is needed. First, this study should be replicated to test the accuracy of the procedure and the findings. Also, the study should expanded to other geographic locations to determine if changes are needed in the procedure.

The second area of additional research is needed in determining tha affects a change in elevation would have on the procedure.

Lastly, once the procedure and the subsequent designs of reconstructed watersheds have been more thoroughly tested, a reconstructed watershed should be placed on the ground and monitored. This is perhaps the only way of truely assessing if erosion is minimized.

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