WATERSHED RECONSTRUCTION DURING THE REHABILITATION OF SURFACE MINED DISTURBANCES

by

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CHAPTER ONE: INTRODUCTION

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In the past few years, the United States has increased coal production to help alleviate the diminishing supply of other fuel sources. Most of this increase in coal production has taken place in the western United States where thick seams can easily and economically be removed through area strip mining. The increase in coal production has created conflicts because of the destructive nature of surface mining.

As a result of those conflicts, the 1977 Surface Mining Control and Reclamation Act was passed. Some of the purposes for the legislation were:

> 1. to balance the need for mining (especially surface mining) of the materials essential to the Nation's energy and economic life with human and environmental concerns.
>
> 2. to protect society and the environment during the surface mining process.
>
> 3. to assure that reclamation occurs to the greatest extent possible during the mining operations (ASLA, 1978, p. 4).

Thus, today rehabilitation is required on all areas disturbed by surface coal mining.

The Problem Area

Water pollution caused by erosion is a major concern of any surface mining operation. Erosion takes place during all phases of the mining process, including the development of roadways, the clearing of areas to be mined, the process of mining, and the rehabilitation of mined lands (Law,1984).

Erosion during the rehabilitation process usually occurs during the first year and between the grading operations and the establishment of a vegetative cover. Past research on the reduction of sediment during this time period has concentrated on surface manipulation or mulching methods used to help establish vegetation. Recently, more attention has been placed on reconstruction of a watershed which is in dynamic equilibrium with the pre-mined site conditions. Some researchers feel that erosion will be minimized if the post-mined watershed is designed to include the pre-mined drainage characteristics. Both the U.S. Geological Survey and the Wyoming Department of Environmental Quality have indicated that watershed reconstruction is an important area for mine rehabilitation research in Wyoming. They are both beginning investigations of their own.

The Problem Definition

Stable watersheds are in a state of dynamic equilibrium, where the erosive forces are approximately equal to the forces which resist erosion. Fluctuations in climate and other factors create the dynamic qualities of the stable state. Erosion is minimized when a watershed is in such a state.

The time it takes for a rehabilitated site to regain its dynamic equilibrium affects the amount of erosion expected from the site. Thus, if that time could be reduced, the amount of erosion could be reduced as well.

Three studies were used as a guide for this study. In 1979, Schaefer, Elifrits, and Barr conducted a study called "Sculpturing Reclaimed Land to Decrease Erosion" involving three post-mined watersheds in Missouri. Their study investigated post-mined drainage patterns, drainage densities, and stream profiles. The conclusion was that reclaimed surfaces, even those reclaimed to an acceptable specification, had a less random drainage pattern, a lower drainage density, and a convex-shaped slope profile.

As a result, unacceptably high amounts of erosion existed and would remain until the reclaimed area reached its dynamic equilibrium. To minimize the amount of potential erosion, Schaefer et al. suggested that the reclaimed land be sculptured to approximate the natural surface in its state of equilibrium. That required equalling pre-mined random drainage patterns, the drainage density, and the concave channel profiles.

Another study on which this research was based was Divis and Tarquin's 1981 study "Geohydrologic Regime of the Powder River Basin". Divis and Tarquin investigated different methods of watershed analysis and concluded that a numerical regime characterization was the best method for analyzing watersheds. From that conclusion, base data for watersheds in the Powder River Basin were collected. The information gathered was on drainage density, stream gradient, valley slope basin area, soil characteristics, vegetation characteristics, infiltration rate estimates, meander morphology, and channel characteristics. Empirical regime equations for the Powder River Basin were then derived from that data.

Special attention to the parameters affecting the formation of the smallest or first order channel was given in the Divis and Tarquin study (1981). The researchers felt that these basins represented the majority of runoff and sediment loading within the drainage network. A similar drainage basin was the "zero order basin" in the Schaefer et al. (1977) study. It was an essential part of the watershed analysis and reconstruction procedure.

The last study was also written by Divis in 1981, "Commentary, WDEQ Guidelines No. 8 and No. 9". In this report, a general procedure was suggested to design a reconstructed watershed.

Scope of Study

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. Included in this study was:

1. A literature review of surface coal mining, legal requirements for coal mining and rehabilitation, and hydrologic parameters which affect the natural development of watersheds.

2. An analysis of the Schaefer et al. (1979), Divis and Tarquin (1981), and Divis (1981) studies and their proposed watershed reconstruction procedures.

3. The development of a step-by-step procedure to design reconstructed watersheds.
4. An analysis of the procedure developed through the use of a case study.
5. A revision of the step-by-step procedure to include the findings of the case study analysis.

It was not the intent of this study to develop the only procedure for the design of a reconstructed watershed. Rather, the intent was to develop one procedure which could be used and to determine some of the problems a designer may encounter upon using it.

CHAPTER TWO: BACKGROUND

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History of Mining

Ancient mining has been closely linked with development patterns. Often, the reason for exploration was to obtain minerals not readily available. For example, the Romans traveled far into Britain to obtain tin and iron ore for their extensive smelting operations.

Exploration of the new world also came from the primary interest in the discovery of minerals and precious metals. The first Spanish explorers came to find golden riches and discovered them in Mexico. The English explorers also came with the intent of finding gold. Instead, they discovered iron ore. The earliest shipment of iron ore took place in 1608 from Jamestown, Virginia, to Bristol, England. Soon, steady shipments of iron ore from the colonies provided England with most of her needs. Copper and lead were discovered in the late 1600's and early 1700's (NAS, 1969).

The discoveries of minerals in the new world allowed countries such as England and the United States, to step forward in changing from an agrarian society to an industrial society in the 1800's. Before that time, when the colonies were first developing, the mining of fossil fuels for energy was unnecessary because of the vast forests. The forests provided wood, an easily accessible fuel source. Wood could be turned into charcoal, a fuel source much more familiar than coal. The first recorded use of coal was not until 1702 in Virginia when a license was granted to a small forge to use coal (NAS, 1969). The mining of coal was first recorded about 1750 with a shipment of 32 tons from Virginia to Boston, New York, and Philadelphia (Weaver, 1981).

It must be realized that mining and the production of minerals in America was diminished due to the English export policies. The stifled mineral development in America changed after independence was gained and the United States controlled her own development.

With the industrial revolution and an increase in population, the use of fossil fuel grew. However, it was not until the 1850's that coal consumption exceeded wood as the main energy source in the United States (Weaver, 1981). Oil was not discovered in large amounts in the United States until 1859 in Titusville, Pennsylvania (Petulla, 1977). The primary use of oil at that time was for kerosene and gas lamps. Thus, coal continued to be the most important source of energy until after World War II.

It was the invention of the automobile that once again changed the American lifestyle and thus, changed the type of fossil fuel consumption from coal to petroleum. America's dependency on petroleum grew, and in 1950 consumption of oil surpassed that of coal. Three years before, in 1947, the United States started importing more oil than it exported (Weaver, 1981).

The consumption of petroleum continued at a fast rate until

1973 when the Arab oil embargo occured. Once an inexpensive source of fuel, petroleum doubled in price within a year. Because of the oil embargo, Americans began to take a closer look at their fuel consumption. As a result, President Nixon declared that the U.S. must strive for self-sufficiency in its use of energy.

Striving for self-sufficiency caused an increase in exploration and extraction for all fuel sources. Because 80 percent of fossil fuel in the United States is coal, the country concentrated on coal to provide the necessary energy. It is expected that with the existing resources, coal consumption could continue well into the 21st century. However, in 1981, coal consumption consisted of only 18 percent of total energy consumption (Weaver, 1981). That consumption was primarily for electricity generation east of the Mississippi River.

Along with an increase in coal consumption came a shift in coal mining. Coal mining, once primarily located in the East, shifted to the western states where low sulfur coal existed in seams up to sixty feet thick. Thus, the western resources provided a more economical return on the investment.

American Coal Resources

Coal is generally divided into three types, lignite, bituminous, and anthracite. Lignite is often referred to as "brown coal". Geologically it is thought to be the youngest coal because of its extreme softness. Lignite is the least desirable because it burns quickly and provides the least amount of heat of the three types.

Bituminous coal or "soft coal" is more desirable than lignite. It is usually buried deeper and thus is more compressed providing more heat per unit than lignite. The most desirable aspect of bituminous coal is that it is found in seams up to 60 feet thick.

Anthracite is generally thought to be the oldest coal formation because it is the hardest coal. It has the highest value because it burns the longest and the hottest. Unfortunately it is the least common of the three types.

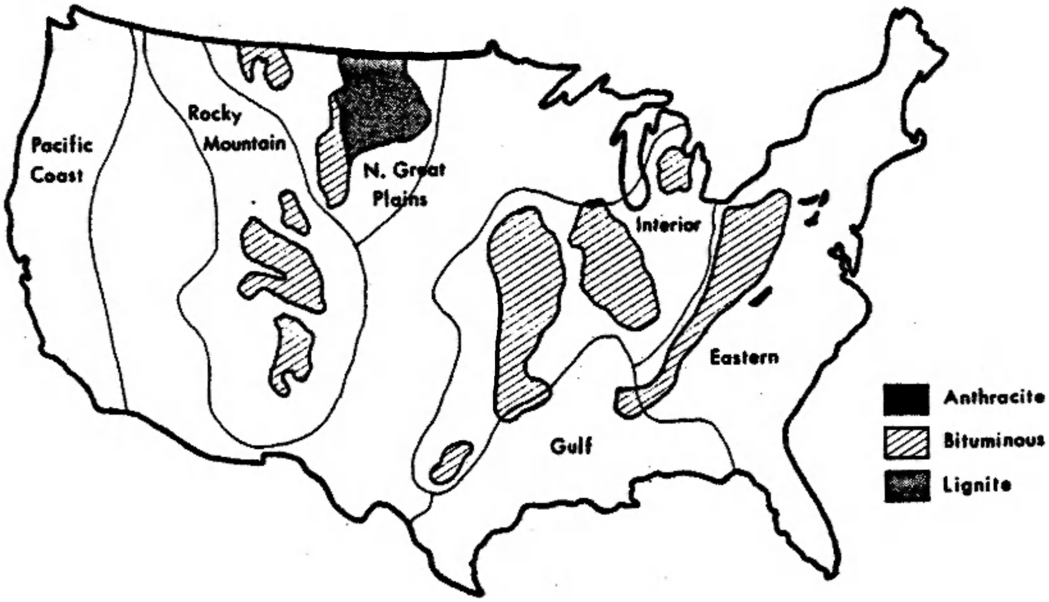

Figure 2:1 American Coal Resources

(National Geographic, 1981, p.62) (Law, 1984, p. 5)

The coal resources are fairly well distributed throughout the United States. Differences in physiographic regions create differences in the mining methods and the amount of coal possible to extract. In order to help define coal mining, the U.S. has been divided into six mining provinces as illustrated in Figure 2:1.

The rolling and mountainous landform of the Eastern Province limits mining to primarily contour strip mining. Area strip mining is common in the flat and the gently rolling terrain of the Interior and Northern Great Plains Provinces. The varying topography of the Rocky Mountain and the Pacific Provinces makes it impossible to determine a common mining method (Law, 1984).

Like the different mining methods employed in each province, reclamation techniques also change upon the physiography and hence the mining method. The term "reclamation" is often used as an all encompassing term to describe the concept of landscape reconstruction. The three terms below more aptly describe the possibilities in reconstructing the landscape.

> "Restoration" implies that the conditions of the site at the time of disturbance will be replicated after the action,
>
> "Reclamation" implies that the site is habitable to organisms that were originally present or others that approximate the original inhabitants,
>
> "Rehabilitation" implies that the land will be returned to a form and productivity in conformity with a prior land use plan including a stable ecological state that does not contribute substantially to environmental deterioration and is consistent with surrounding aesthetic values (NAS, 1974, p. 11).

Typically restoration is not possible because the act of mining so dramatically changes the site. Reclamation and rehabilitation are more possible to achieve. The determination of which one to use is dependent upon the goals of society (NAS, 1974).

Reclamation Legislation

Reclamation of disturbed surface mined areas is a recent development. Throughout history, the need to restore land after it had been used was not seen as necessary or as a worthwhile expenditure of money. Conservation of resources had not been emphasized until the 1960's except by a few enlightened individuals. Thus, it took years before reclamation of surface mined areas was required by law.

The first reclamation laws passed were in the 1940's and 1950's in the heavily mined eastern states such as West Virginia, Pennsylvania, and Illinois. Reclamation at that time was a police power of the state, allowing state governments the right to exercise a reasonable control over mining procedures because they affected the good of society. In 1948, the requiring of reclamation was taken to court to determine if it was a valid exercise of the state's police power. The controversy was taken to the Pennsylvania Supreme Court which upheld the state's right to regulate reclamation (Fridirici, 1981). That decision opened the doors for further reclamation legislation.

In the western states, legislation requiring reclamation was much slower to be enacted. The first law governing reclamation in the west was a 1967 law in Montana. This law did not set standards, but offered incentives to reclaim in the form of tax credits. It was subsequently updated in 1969 and 1971. In 1973 a new law was passed with more stringent requirements (NAS, 1974).

By 1972, seven western states had passed laws concerning reclamation. These include: Montana, Colorado, Wyoming, North Dakota, South Dakota, Washington, and New Mexico. The trend of the laws in the west was that they were more stringent than the eastern laws which preceeded them. These laws also varied with the types of minerals affected. In Colorado, only coal and construction aggregrates were subject to regulation, whereas in Wyoming, any material mined was subject to regulation.

Until the mid seventies, the Federal Government had no law regulating the reclamation of mined-lands. In 1977, the Federal Government passed the Surface Mining Control and Reclamation Act. This act established minimum standards for the reclamation of lands disturbed by surface mining of coal.

The basis of the law was both environmental and economic. First, the government recognized that surface coal mining adversely affected commerce and public welfare through the destruction of existing land uses, pollution of water, damage of natural beauty and habitats, and creation of hazards to life and property (Wagner, 1979).

Because of that finding, the federal government recognized that:

1. Environmental protection standards must be established,

2. The primary responsibility for creating and regulating mining and reclamation must rest with the states because of the diversity of terrain and other physical characteristics,

3. Minimal national standards must be established to eliminate economic advantages or disadvantages among states due to a varying degree of legislation, and

4. A procedure must be created to enable the reclamation of mines abandoned before the enactment of the legislation (Wagner, 1979, p.344).

In addition to setting minimum standards, the Surface Mining Control and Reclamation Act created the Office of Surface Mining (OSM), to regulate and enforce the requirements of the act. One of the first tasks outlined for the OSM was to approve or disapprove state laws and programs developed as a requirement of the federal legislation.

Each state was required to meet the minimum standards set forth by the federal legislation but was allowed to create more stringent regulations if it so desired. The OSM was required to submit a federal program for any state which failed to submit a program (Wagner, 1979).

Wyoming's Legislation

Wyoming passed its first law governing reclamation in July of 1973. This law was called the Wyoming Environmental Quality Act. This law governed material "mined" within the state that disturbed more than 2 acres/year (NAS, 1974). This law also required that mining companies submit a bond prior to mining not to exceed $10,000 and a permit fee not to exceed $2,000. The Wyoming Department of Environmental Quality (WDEQ) was created for the purpose of regulating and enforcing the law (NAS, 1974).

After the enactment of the federal law, the WDEQ created a set of rules and regulations to which all mining companies must adhere. The rules and regulations cover topics such as the permit application procedures, the environmental protection performance standards, the mineral exploration procedures, the bonding requirements, and the designations for lands unsuitable for surface coal mining (WDEQ Rules & Reg., 1983).

Drainage Network Characteristics

To place a reconstructed watershed on the reclaimed surface, the pre-mined drainage network characteristics must be analyzed to determine whether or not the watershed is in a state of dynamic equilibrium. A quantitative analysis of watersheds provides the information needed to characterize the state of dynamic equilibrium.

Quantitative analysis of watersheds began with Horton's 1945 study, "Erosional development of streams and their drainage basins: Hydrophysical approach to quantitative morphology". Drainages and their physiographic features were compared, contrasted, and analyzed in a quantitative manner through stream ordering. Through the years, Horton's stream ordering method has been modified. A stream ordering method suggested by Strahler in 1952 is now generally accepted due to its simplicity and is described below.

The first aspect of quantitative analysis is stream ordering which classifies streams on the basis of bifurcation (branching), see Figure 2:2 (Horton, 1945). This system begins with the smallest channel, highest in the drainage basin and assigns it a number "1". When two streams of the same order join, a stream of the subsequent higher order is created. If a stream of a lower order joins a stream of a higher order, the higher stream number remains the same. Only when two streams of the same order join, does the stream order increase.

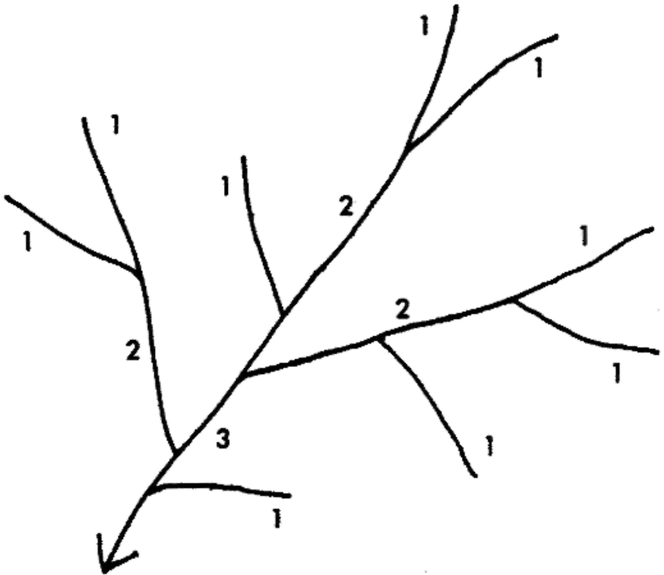

Figure 2:2 Stream Ordering

The advantage of the stream ordering system is that once the channels are ordered, additional data can be collected and compared. Through a few simple additional measurements, Horton began to realize that the stream characteristics, such as numbers of streams, stream lengths, and stream slopes, followed a geometric progression when compared to stream order. When plotted on semilogarithmic paper, the comparisons very close to straight lines (Horton, 1945). These relationships became the basis for the law of stream numbers, stream lengths, and stream slopes which are the root of quantitative drainage basin characterization. Additional studies conducted since Horton first suggested the laws of drainage composition support his findings. A study which looks at the relationships of stream numbers, stream lengths, stream slopes, and basin areas is called a Horton Analysis.

The Law of Stream Numbers states that the numbers of streams of different orders in a given basin closely approximate an inverse geometric series. The ratio created is called the bifuraction ratio (Horton, 1945). This law has been expressed numerically as:

$N_{w-1} \cong R_B, \ w = 2,3 \ldots \Omega$

N = Number of Streams

R_B = Bifurcation Ratio

w = Stream Order

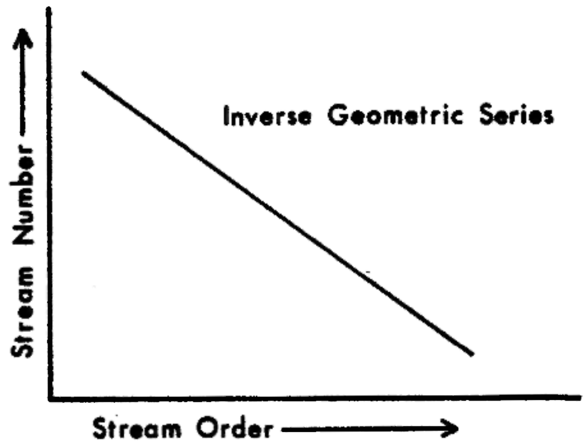

Figure 2:3 Law of Stream Numbers

(Smart, 1962, p. 309)

In layman's terms, the lower the stream order, the higher the number of streams per order will occur.

The Law of Stream Lengths is that the average lengths of streams of each of the different orders in a drainage basin closely approximate a direct geometric series. The ratio created is the stream lengths ratio (Horton, 1945). This law is expressed numerically as:

$\bar{L}_w / \bar{L}_{w-1} \simeq R_L , w = 2,3 \ldots \Omega$

$\bar{L}$ = Ave. Stream Length

R_L = Stream Length Ratio

w = Stream Order

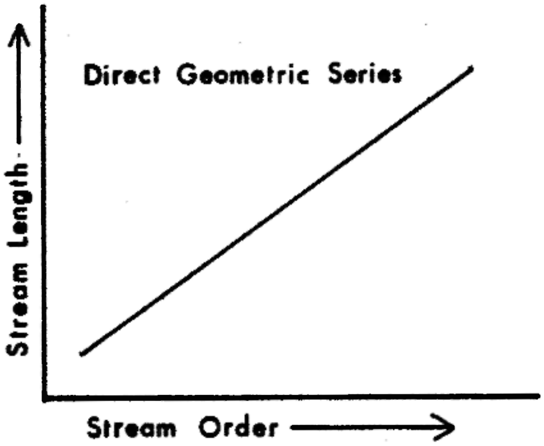

Figure 2:4 Law of Stream Lengths

(Smart, 1962, p. 309)

The stream length can be obtained by dividing the average stream length of any order by the average stream length of the next lower order (Horton, 1945). Once again, the lower the stream order, the shorter the length of stream.

The Law of Stream Slopes was also investigated by Horton and was found to be expressed by an inverse geometric series. Thus, the lower the stream order the steeper the stream gradient. This was shown by plotting stream channel profiles. A stable stream channel, one that is in a dynamic equilibrium, generally has a concave profile (Horton, 1945).

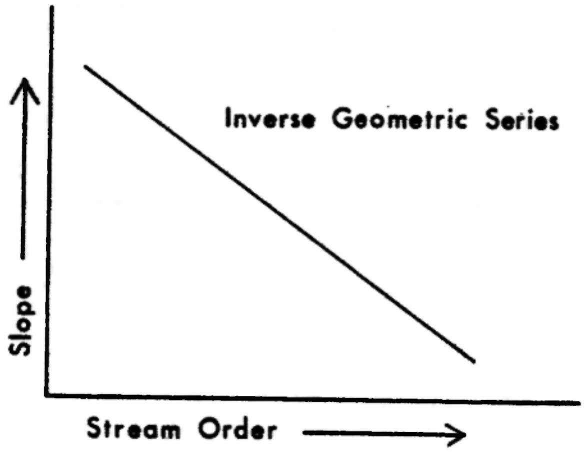

Figure 2:5 The Law of Stream Slopes
(Horton, 1945, p. 295)

The slope of the stream profile indicates the stability of a stream channel. Four stream and side slope profiles occur naturally:

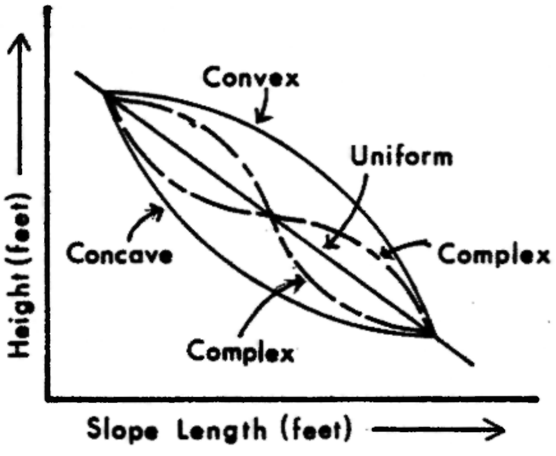

Figure 2:6 Slope Profiles
(Schaefer et al., 1979, p. 100)

1. Concave slopes are least affected by erosion, yield the least amount of sediment, and change shape slower than other profiles,
2. Convex slopes erode most rapidly, yield the most sediment, and change shape faster than other profiles

3. Uniform and complex slopes are affected to an intermediate degree although long uniform slopes can be severly eroded in a single rainstorm,

4. Slopes in reclaimed material will tend to develop concave profiles in their mid to lower sections given sufficient time,

5. The steepness of the toe of the slope is most significant in affecting the rate of sediment yield and the rate with which the slope will change shape (Schaefer et al., 1979, p. 100).

Later, in 1956, Schumm suggested an additional law in a similar vein to those Horton suggested. It is the Law of Drainage Areas. This relationship closely approximates a direct geometric series when the average drainage area of each of the stream orders is compared to the stream orders. Drainage area is measured in square miles in a horizontal plane. This law is expressed numerically as:

$\bar{A}_w / \bar{A}_{w-1} \simeq R_A$, $w = 2,3 \dots \Omega$

$\bar{A}$ = Ave. Drainage Area

R_A = Area Ratio

w = Stream Order

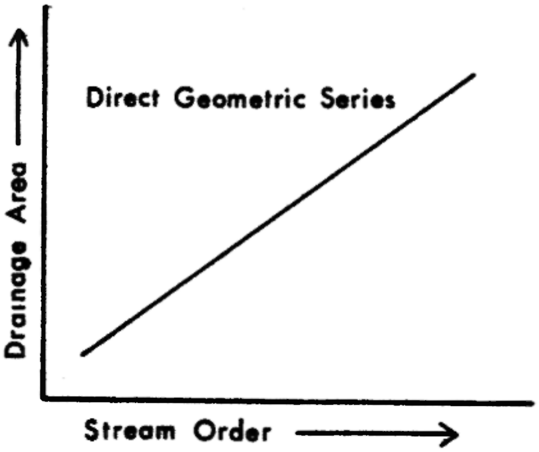

Figure 2:7 Law of Drainage Areas

(Smart, 1962, p. 310)

A measurement derived from and closely associated with drainage area is drainage density. It describes the degree of drainage development by adding the total stream length within a basin and dividing by the basin area. Numerically it is expressed:

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

L = Length of Streams, in miles

A = Area of the Basin, in square miles

Figure 2:8 Drainage Density

(Horton, 1945, p. 283)

One problem associated with the laws of drainage composition is determining the appropriate scale of the inventory map. Optimally, a first order stream is the first initial cut of a channel after overland flow takes place, high up near the basin divide. Such channels however, may not be shown on a particular map, depending upon the scale. Thus in past hydrologic studies, researchers have primarily used the USGS 1:24,000 topographic maps as a basis for stream ordering and data collection. Horton stressed that intermittent streams must be included in stream ordering because although they do not contain continuously running water, they do carry water at the critical morphological times, such as spring runoff and intense thunderstorms (Horton, 1945).

Caution must also be used when employing any of these quantitative characteristics in describing a particular drainage pattern. The drainage pattern must not be confused with drainage network characteristics. Horton pointed out that basins with identical stream numbers, and lengths may have a dendritic, rectangular, or radial pattern. In addition, drainage basins with the same drainage density could have a variety of stream numbers, lengths, and areas. It is the composition of the drainage network which has a high degree of significance, not the drainage pattern (Horton, 1945).

Erosion on Mined Lands

To hydrologists, ecologists, and other natural scientists, the erosion process by water is not only natural, but beneficial. Periodic inundation of a river's flood plain rejuvenates soil with needed nutrients. But there is a difference between natural erosion which is the "geologic norm" and that which has been accelerated by humans (Strahler, 1956).

Erosion caused by surface mining activities is well above the geologic norm. In some cases, erosion from surface mines is 2,000 times higher than from an undisturbed forest (Law, 1984). Erosion from surface mining occurs in all stages of mining, from the initial clearing and grubbing to the rehabilitation. Because of the problems caused by this accelerated erosion, the sediment produced is classified as a pollutant. Thus, methods of reducing erosion by water are an important areas for research.

Erosion occurs when the energy in the surface flow of water is greater than the energy which resists erosion (Horton, 1945).

There are four types of erosion:

Splash:	is the loosening of soil particles caused by the impact of raindrops in saturated soils.
Sheet:	is the removal of a fairly uniform layer of soil from overland flow of water. This layer of overland flow is very thin, usually less than 1" in depth.
Rill:	is the erosion caused by the creation of numerous small channels only several inches deep. Rill channels generally run relatively parallel to each other, in new terrain absent of vegetation.
Gully:	is the erosion caused by the creation of larger channels. The channels can range in depth from 1 foot to 100 feet (Law, 1984) (Horton, 1945).

There are three processes involved in surface erosion:

1. The tearing loose of soil material,
2. The transport of material eroded by sheet flow,
3. The deposition of material in transport.

(Horton, 1945)

The processes of tearing loose and transport always take place within a watershed. Deposition can occur within or outside of the watershed in which the other two processes occur.

There are four factors which govern soil erosion:

1. The surface's initial resistance to erosion
2. The infiltration capacity of the soil
3. The intensity of the rainfall
4. The velocity and energy of the overland flow

(Horton, 1945)

The initial resistance of the surface to erosion varies depending upon the amount of vegetation present and the soil characteristics. The presence of vegetation is the most important factor in the initial surface resistance to erosion. It tends to break the force of the raindrops reducing the impact and the splash erosion. The root system also acts as a binder for soil particles. However, in the case of mine rehabilitation, vegetation is not present to increase the surface resistance to erosion.

Soil texture can affect the surface resistance to erosion. Finer particle sizes tend to attract each other creating a resistance. Soil texture also affects the infiltration capacity.

Infiltration capacity is the maximum rate at which a soil can absorb rainfall. The factors which determine the infiltration capacity of a soil are: soil texture, soil structure, vegetal cover, biologic structures, moisture content, condition of the soil surface (Horton, 1945). "Nearly all the factors which control the resistance of soil erosion also control the infiltration capacity. In many instances, the factors which tend to promote a high resistance to erosion also tend to reduce the infiltration capacity" (Horton, 1945, p. 318). Thus the infiltration capacity for a fine grained uncemented sand is high whereas its initial surface resistivity is low. The infiltration capacity for a cemented clay is low whereas its initial surface resistivity is high. In either case the result is a lowered potential for erosion (Horton, 1945).

The intensity of rainfall affects soil erosion through splash erosion and the creation of overland flow. The impact of raindrops can dislodge soil particles, thus starting the erosion process.

Rainfall is an uncontrollable input in the erosional and channel formation process because it is not subject to management by humans (SEAM, 1980). In the Powder River Basin, summer thunderstorms are the most significant type of precipitation. The storms are generally short and intense. The amount of precipitation the summer thunderstorms produce is quite variable. Equal amounts of precipitation are not necessarily dropped throughout a watershed (Craig and Rankyl, 1979). This creates variability in the erosional and channel formation processes.

Overland flow, the last factor which governs soil erosion, is directly related to the slope and roughness of the surface. Overland flow occurs when the rainfall intensity exceeds the infiltration capacity. Any existing vegetation will reduce the velocity of the overland flow.

Generally the force of the overland flow increases as it travels downslope. The most erosion occurs in the steepest portion of a hillside which is neither at the crest nor at the bottom.

Each of the four factors that govern erosion are related to each other. They all work together to create conditions which inhibit or create erosion.

Channel Formation Through Erosion

In Horton's (1945) study, the formation and morphology of rills on exposed lands were examined. Although rills are only inches deep, the principles of channel formation remain constant throughout a drainage system. However, in larger systems, variations will be greater due to larger differences in rainfall, infiltration capacity, surface resistance, and slope.

The first concept described by Horton (1945) in the formation of channels is the "belt of no erosion". Along the ridgeline of any watershed is an area where the eroding force has not exceeded the resistive forces. The distance from the ridgeline to where the erosive forces exceed the resistive forces is called the "critical distance". The belt of no erosion is no wider than the critical distance. Figure 2:9, graphically describes the concepts of critical distance and the belt of no erosion.

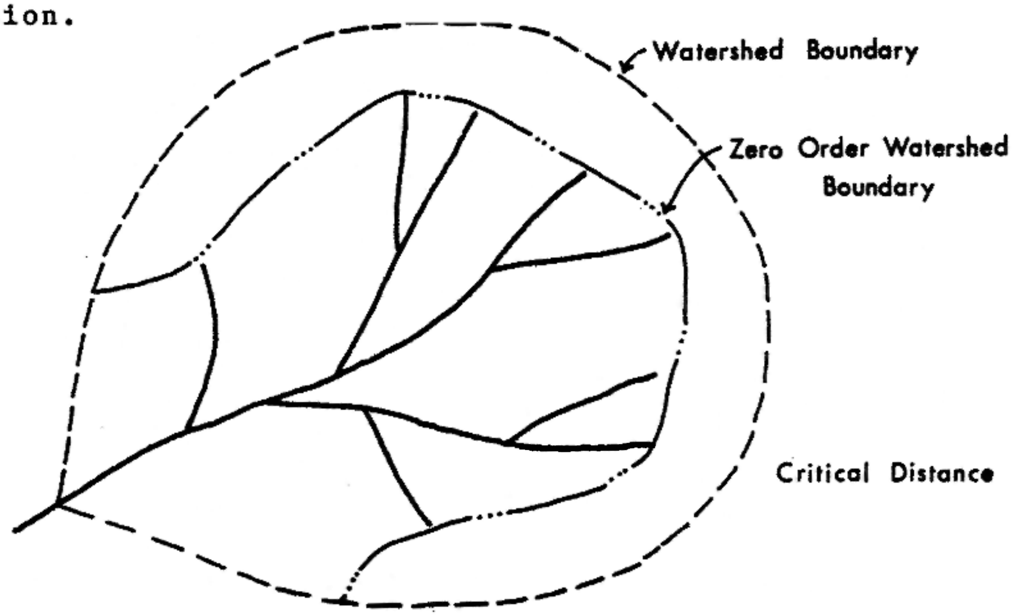

Figure 2:9 The Zero Order Watershed

(Horton, 1945, p. 344)

Within the critical distance, overland flow exists. However, the force of the flow has not exceeded the resisting forces, thus creating the belt of no erosion.

In reality, the "belt of no erosion" is incorrect. Sheet erosion will always take place where there is overland flow. Thus, it is assumed that the belt of no erosion actually refers to the area where channel erosion does not occur. Because of that, this study has changed the name of the "belt of no erosion" to the "area of the zero order watershed". Zero order indicates that no channelized flow has occurred.

Surfaces which carry overland flow are not smooth and uniform. Often, the sheet flow itself is not uniform, tending to travel down slope in waves rather than a constant flow. Because of the irregularities in overland flow, concentrations in flow occur. Rill channels develop where the concentrations occur.

Rilled surfaces are generally covered by relatively uniform, closely spaced, parallel channels. The same irregularities that exist in an area of overland flow also exist in rilled surfaces. Thus, eventually rills will run into each other. That process is called "cross grading". Eventually, one rill will become the dominant channel. According to Horton (1945) those rills which develop earliest, have the greatest length, and can absorb cross grading competition, have the best chance for survival.

This concept of rill development can be applied to any surface which has been exposed, no matter the size. Horton (1945) suggests that if the entire land mass of the United States were exposed, the same process described above would occur, assuming there were no variations in soil and rainfall. "The process of stream development will continue to erode headward until there is no land surface above the mouths of the original tributaries where the length of overland flow exceeds the critical length" (Horton, 1945, p. 347).

Mining and Rehabilitation Methods

The characteristics of the mining and reclamation methods used can determine some of the success of the rehabilitation effort.

The recontouring of spoil piles and the resultant landscape depends upon the type of equipment used and the time of year the recontouring takes place. Generally reclamation efforts by scrapers have much higher compaction than that of bulldozers. Often complications are created when land is reclaimed during the winter months, when large clasts of frozen soil are buried. In that case, compaction is virtually impossible to achieve, because in the warmer months, the frozen clasts thaw creating an area of subsidence (Dollhopf, 1983).

General area wide subsidence of 1 - 3 feet usually takes place the first two years after completion of the recontouring. This settling factor is much less in areas recontoured by scrapers than by bulldozers. Areas recontoured by scrapers in the winter months create the most stable environment.

CHAPTER THREE: METHODOLOGY

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Preliminary Procedure Development

A preliminary procedure for designing reconstructed watersheds was developed using three studies 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 & No. 9" by Divis (1981).

Each study provided insight into the characteristics of a stable watershed. They also suggested methods for analyzing a stable watershed and designing the reconstructed watershed. An analysis of the advantages and the disadvantages of their suggested methods for reconstruction provided the basis for the preliminary procedure development.

A preliminary step-by-step procedure for designing reconstructed watersheds was then developed based on the analysis of the three studies.

The Case Study

A case study was then used to analyze the preliminary procedure. This method of investigation has been used in past studies concerning watershed development on reclaimed land and was considered suitable for this study.

The Powder River Basin was chosen as the case study area. This decision was based on the large amount of surface coal mining in the area and because the Divis study was based on data collected in the area.

Upon preliminary investigation for site selection, the U.S. Geologic Survey Office in Cheyenne, Wyoming, indicated that they were conducting a hydrologic survey of the Eastern Powder River Basin. It was hoped that the U.S.G.S. data could be used to substantiate the findings in this study. However, the data was not available until after the completion of this study.

The Belle Ayr coal mine, owned by AMAX Coal Company in Gillette, Wyoming, was chosen for the case study site.

The Belle Ayr mine was chosen primarily because AMAX Coal Company was willing to provide base data necessary for the study. The base data AMAX furnished was:

1. A topographic map of the pre-mined permit area at a scale of 1" = 500', and a contour interval of 5 feet.

2. A diazo print aerial photo of the pre-mined permit area showing soil types, at a scale of 1" = 500'.

3. A map showing the Caballo Creek watershed indicating stream orders, at a scale of 1" = 2000'.

4. Written base data as provided in the hydrology and soils sections of the permit application for the Belle Ayr Mine.

In addition to the data furnished by AMAX Coal Company, the Bureau of Land Management Office in Cheyenne, Wyoming, provided orthophoto quads which included the mine site.

Procedure Analysis and Findings

The preliminary design procedure was then analyzed from the data collection through the final design of the reconstructed watershed. The analysis focused on problems encountered during each step of the process, to see if the procedure could be adjusted to accommodate or avoid the problems encountered. An adjusted procedure was then developed which included the findings of the procedural analysis.

CHAPTER FOUR: PRELIMINARY PROCEDURE DEVELOPMENT

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Three studies are used as a guide for the preliminary procedure development. In 1979, Schaefer, Elifrits and Barr conducted a study called "Sculpturing Land to Decrease Erosion." In 1980, Divis and Tarquin investigated the "Geohydrologic Regime of the Powder River Basin". Later, in 1981, Divis wrote "Commentary of WDEQ Guidelines No. 8 and No. 9" which suggested a design procedure for reconstructing watersheds during reclamation.

The Schaefer, Elifrits, and Barr Study

Schaefer et al. (1979) recognized that erosion from reclaimed land disturbs revegetation and increases sediment which must be contained in sediment ponds. Thus, to understand the hydrologic reasons for erosion on reclaimed lands, Schaefer et al. examined three reclaimed watersheds in Missouri, and compared their characteristics to undisturbed watersheds.

The first step in the study was to determine the characteristics of stable watersheds. A stable watershed is in dynamic equilibrium where "those forces giving rise to channel development, are in approximate equilibrium with the forces resisting erosion" (Schaefer et al., 1979, p. 99). Thus, erosion is minimized when a drainage network is in dynamic equilibrium.

Drainage density and the zero order watershed concepts are used to aid in designing the reconstructed watershed by indicating the state of equilibrium which should be achieved. The drainage density, as described in chapter two of this thesis, must be used in determining the number and length of stream channels needed to drain the area.

The zero order watershed is "the minimum drainage area from which the runoff produced has sufficent force to initiate channel development" (Schaefer et al., 1979, p. 101). The researchers found that the area of the zero order watershed is a "function of the parameters which produce and resist erosion", (p. 101).

The Schaefer study chose three sites in Missouri and interpreted and analyzed the pre-mined and post-mined drainage patterns using aerial photography. Upon comparison, it was determined that:

1. Pre-mined watersheds exhibited concave channel gradients whereas the post-mined watersheds exhibited convex channel gradients,
2. All the post-mined topography varied significantly from the pre-mined topography,
3. Post-mined drainage density had decreased from the value of the pre-mined topography (Schaefer et al., 1979).

In conclusion this study found that "when the runoff concentrates in the drainage channels, these channels will erode headward until the entire surface slope contains an integrated random pattern of channels in dynamic equilibrium with the existing environment", (Schaefer et al., 1979, p. 103).

This leaves the question, how should the drainage network be designed in order to accelerate the state of dynamic equilibrium? Schaefer et al. (1979) proposed that the "disturbed mined-land ought to be regraded so as to approximate the sculptured surface of a natural terrain with numerous branching, randomly oriented channels, and concave drainage profiles and side slopes", (p. 106).

In order to approximate the terrain of a watershed in dynamic equilibrium, three approaches were suggested. The first approach was to estimate the average area of the zero order watersheds from the pre-mined topography. The second approach was to estimate the first order drainage basin areas from aerial photos or maps. The third approach was to use an adjacent area of similar terrain to characterize the pre-mined natural watershed and thus, the reconstructed watershed. In all three approaches, Schaefer et al. (1979) suggested that the stream layout should be a dendritic pattern, that the drainage channels should have parabolic cross sections, and that the drainage and side slope profiles should be concave.

The Divis and Tarquin Study

The Divis and Tarquin study investigated stream parameters to appraise the natural stability of stream channels and their drainage basins. By appraising the pre-mined natural stability, reclamation efforts could be enhanced to reduce the time of obtaining a new equilibrium to a minimum.

There are three approaches Divis and Tarquin felt could be used to design watersheds on reclaimed surfaces: the carbon copy, the terrain comparison, and the regime characterization. The carbon copy approach is just that, a complete restoration of the pre-mined landscape, including hills and valleys in the same pre-mined location. In the terrain comparison, the general topographical characteristics for the reclaimed site come from a nearby area with similar pre-mined characteristics. The regime characterization assumes that certain parameters characterize the stability of a watershed. Through those parameters, a numerical description of stability can be determined (Divis & Tarquin, 1981).

Divis and Tarquin feel that the regime characterization is the best method of the three to use in the design of the reclaimed surface. The carbon copy is virtually impossible to achieve because of the dramatic change of the landscape during mining. In the Powder River Basin, the post-mined landscape is generally 20 to 100 feet lower than the pre-mined surface. It is difficult to determine if the landscape used in the terrain characterization is truly similar enough to use. Thus, the regime characterization, which uses the pre-mined landscape to determine a stable hydrologic system seems to provide the greatest potential for success in reclaiming the disturbed landscape.

The first order drainage basin, that basin which drains into the first order stream is considered very important in reconstructing the the drainage system. This is because the first order basins supply the majority of runoff and sediment loading within the drainage system. Restoring first order basins smaller or larger than their original hydrologic function, could lead to increased erosion and sediment loading (Divis & Tarquin, 1981).

In conclusion, the Divis and Tarquin study indicated that the use of the regime equation analysis permits the appraisal of the natural stability of a drainage basin as a whole. The advantage to this method enables the design of the reconstructed watershed to be a continuation of the downstream system. In this way, the time taken to return the hydrologic system to its state of dynamic equilibrium can be reduced.

The Divis Study

In the third study, "Commentary: WDEQ Guidelines No. 8 & No. 9", Divis (1981) suggested a design procedure to be used in reconstructing watersheds utilizing a regionalized data base. The procedure is:

1. Establish macrotopography of reclaimed surface.
2. Locate and design major channels entering and exiting the property.
3. Delimit major tributary basins.
4. Determine slope length relief difference sectors appropriate for various drainage densities.
5. Populate major tributary basins with successively lower order subbasins.
6. Modify topography to conform to lower order basin drainage net.
7. Repeat items 5 and 6 until first order basin structure consistent with the regime relation or regional drainage density is reached.
8. Design the lower order channels.
9. Determine soil loss and sediment balance for the reclaimed surface" (p. 18).

Procedure Analysis

The Divis (1981) procedure above is a good comprehensive list of the general steps needed to design a reconstructed watershed. The general nature of the procedure has advantages in that it can be used anywhere. That same general quality however, limits the success of the procedure when applied to a specific site.

Another problem with the Divis (1981) procedure is the source of data. Divis feels that a common data base should be available for use by the mining companies. In this way, much of the repetition which currently exists between mining companies during the data collection could be eliminated. Once completed, the USGS study of the Eastern Powder River Basin could be used as a common data base, if the information gathered is detailed enough.

This study, however, must assume that conditions are as they exist now, that no available data base exists and that each mining company must collect its own data. Regardless of where the base data come from, each mine site must be inventoried to determine site specific characteristics. Therefore, data collection must be incorporated into the procedure.

A major concern with the Divis (1981) procedure is that the importance of the first order basin is not emphasized enough. According to Divis and Tarquin (1981) "the hydrologic function of a first order basin is critical during restoration" (p. 51). However, it is the last watershed to be delineated within the procedure. Thus the error which is bound to be incorporated in the design is most likely found in the smallest and most critical drainage basin.

The method suggested by Schaefer et al. (1979) starts with delineating the zero order basins. That procedure is just opposite the procedure suggested by Divis (1981). However, by starting with the zero order watershed, the Schaefer et al. (1979) procedure assumes that the overall drainage density will be met. This may or may not be true.

Finally, the Divis (1981) procedure is difficult to understand. Broad statements such as "delimit major tributary boundaries" (p. 18) do not provide enough direction. What defines a major tributary? How should the tributary boundaries be defined?

A procedure of this sort must be easy to understand and clear enough in its description so as not to create questions in the middle of the design procedure. The Divis (1981) and Schaefer et al. (1979) procedures do neither.

At this point, the subject of using the zero order basin rather than the first order basin area to design the reconstructed watershed must be discussed. It is generally assumed that streams will erode up the valley if the amount of overland flow exceeds what the existing channel can handle (Divis and Tarquin, 1981). 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 is a more accurate indicator of the channel development that the first order basin (Schaefer et al., 1979.

Because of that, the zero order watershed is the basis for the design of the reconstructed watershed.

Preliminary Procedure Development

The following is a procedure developed from the analysis of the Divis (1981) and Schaefer et al. (1979) procedures.

1. Determine the appropriate scale of map for the site.

   The zero order basins must be distinguished in order to provide a detailed set of data. Therefore the suggested scale is 1":500'.

2. Locate all streams and their drainage basins.

3. Locate 3 sample watersheds

   Sample watersheds are those which have a minimum of a third order stream at its outlet. Locate all watersheds that fit that criteria. Then choose three sample watersheds for data collection.

4. Determine the zero order watersheds in the 3 sample watersheds.

   Draw a line connecting the beginning of each first order stream. This delineates the total area of the first order watershed. Calculate the total area by using a planimeter and divide by the number of first order streams. This gives the average area.

5. Measure the following in each sample watershed for each stream order:

    - number of streams
    - stream length
    - stream slope
    - basin area

6. Calculate the following:

    - averages for each order,

      # streams
      stream length
      stream slope
      basin areas
      drainage density

    - averages between the three sample watersheds for each order,

      stream length
      stream slope
      basin areas
      drainage density
      zero order watershed area

7. Collect data from written sources.

    - thickness of coal seam to be removed

    - thickness of overburden

    - difference in elevation between pre- & post-mined landscape

    - soil and overburden characteristics

    - rainfall characteristics

8. Establish the macrotopography of the post-mined landscape

    - locate the high points

    - locate the low points

    - locate streams which enter and exit the site

9. Place a grid the size of the zero order watershed over the entire site.

Take the square root of the average area of the zero order watershed in square feet. That determines the dimensions of a square the size of the average area of the zero order watershed. Then place a grid over the site using those dimensions.

10. Begin to establish first order streams

Each square established by the grid in step 9 must be drained by a stream. That stream may be of any order. Each square established can create a stream or flow directly into an existing stream through overland flow. Use the data gathered in earlier steps to guide the placement of the streams.

11. Establish subsequent orders until the site is drained

Continue to use the information gathered in steps 5, 6, and 7 to guide placement of the rest of the streams. Each square created by the grid must be drained by a stream. That stream can be of any order and can flow through or alongside a square.

12. Establish the topography

Use the calculated pre-mined slopes as a guide to establishing the topography. All the stream profiles must be concave. Use a contour interval of 10 feet to establish the topography. Sections and profiles may be useful in establishing the post mined topography.

13. Repeat steps 3, 4, 5, and 6 for the post-mined topography

14. Compare the data from the pre-mined and the post-mined landscapes

Compare these averages:

stream length
stream slope
basin area
drainage density
area of zero order watershed

15. Adjust the post-mined landscape to more closely reflect the pre-mined landscape

If the post-mined landscape does not reflect the characteristics of the pre-mined watershed, the landscape must be adjusted.

CHAPTER FIVE: ANALYSIS AND FINDINGS

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The Case Study

The Belle Ayr Mine near Gillette, Wyoming was used as the case study site. It is owned and operated by AMAX Coal Company. Production began in 1973 on the 6,280 acre permit.

The Belle Ayr Mine site is typical of the Eastern Powder River Basin. Precipitation ranges from 11" to 23", averaging 16" annually. The majority of the precipitation falls during the summer in intense thunderstorms of short duration.

The topography is low rolling hills and some steep gullies. Slopes range from a relatively flat 5% in stream flood plains up to 25% in the gullies.

Cutting through the Belle Ayr Mine is Caballo Creek. It is an intermittent stream, yet a major drainage in the area.

Because Caballo Creek bisects the site, the overburden within the Belle Ayr Mine is very shallow. The overburden averages 150 feet in depth. The coal seam averages about 75 feet thick. The thick coal seam along with the shallow overburden results in a low overburden to coal ratio. Because of that ratio, the post-mined elevation is lower than the pre-mined elevation.

The shallow overburden also affects the mining procedure. The mining method used in the Belle Ayr Mine is the truck and shovel method. The truck and shovel mining method allows easier grading, contouring, and selective removal and replacement of soils (Wiener, 1980). The overburden is removed from the active pit and then dumped into the pits where the coal has been removed. This mining procedure allows for concurrent rehabilitation and mining. Thus, the topsoil stripped for pit expansion is replaced on the land being rehabilitated without any stockpiling.

The pre-mined landuse was primarily livestock grazing. The vegetation was native grasses and sagebrush. Once the mining is completed, the original land use will be restored.

Preliminary Procedure Analysis

The preliminary procedure developed in Chapter 4 was used to design a reconstructed watershed on the Belle Ayr Mine near Gillette, Wyoming. The success of the procedure was then assessed. Throughout the procedure, problems were encountered from both a practical and a technical nature. The following is a description on a step-by-step basis of the problems encountered and suggestions as to how to alleviate them.

Step One: Determine the appropriate scale of map

The optimal scale of map is one that shows the initial channelization of the overland flow. It is important to locate the initial channelization because that is where the majority of sediment loading within a drainage system occurs.

The Wyoming Department of Environmental Quality (WDEQ) suggests scales in a range from 1":400' to 1":700' at a five foot contour interval as appropriate for collecting base data for the mining permit application. The base map AMAX used for the Belle Ayr mine was at a scale of 1":500'. In addition to the maps at 1":500', AMAX had aerial photos at a 1":250' scale for some parts of the mine.

To show the entire Belle Ayr mine at a 1":250' scale, the size of the map would be approximately 4 feet by 6 feet. That is far too cumbersome compared to a 24" by 40" map at the scale of 1":500' which can easily be placed on a drafting table. When the amount of detail was compared on the two maps, the 1":250' was much clearer. Yet with the addition of an aerial photo at the scale of 1":500' the accuracy was increased and was similar to the 1":250' scale. A 1":700' scale is not recommended because such a scale does not exist on commercially available engineer's or architect's scales.

The USGS office in Cheyenne, Wyoming used a scale of 1":2000' as the base for their hydrologic study in the Powder River Basin. That is the scale of a USGS topographic map. Many past hydrologic studies have also used the topographic map scale which allows easy comparison between studies. However, for a study such as this, the 1":2000' scale is not detailed enough. For example, Tank Battery Draw (Watershed # 1) is a first order stream on the 1":2000'scale map. On the 1":500' scale map, Tank Battery Draw is a fifth order stream.

Therefore, the appropriate scale of map should be 1":500', at a five foot contour interval. This allows sufficient detail while not being too cumbersome and remains within the WDEQ guidelines for the mining permit application.

Step Two: Locate all the streams and their drainage basins

It is necessary to locate all the streams within the site. This is the only way to determine stream orders. The streams were located on the mine site by placing a sheet of mylar over the topographic map and drawing the streams on the overlay in ink.

The location of the streams was aided by an aerial photo of the site provided by AMAX at the same scale as the topographic map. The aerial photo gave an additional reference and allowed greater accuracy in determining the stream locations. Stereo photo coverage at the same scale would provide even greater accuracy.

A number of problems were encountered while locating the streams in the Belle Ayr Mine. First, stock ponds existed. Although it is noted that stock ponds affect the dynamic equilibrium of a watershed, it was determined that the affect was relatively small. Therefore the stream was located through the center of the stock pond as if the pond did not exist.

Second, Caballo Creek was a meandering stream which created a definite flood plain. To a smaller extent, all the streams which flowed into the site also had flood plains. The problem was in locating streams once they flowed into the flood plain. Once in the flood plain, the contour lines no longer indicated the flow line. The streams also disappeared on the aerial photo.

The WDEQ guidelines for gathering hydrologic data on surface water includes information on meander loop characteristics such as wave length and frequency (WDEQ, Guideline No. 8). From this data the average amplitude for the meanders was determined and plotted in the topo map during the permitting procedure. The loss of the contours indicating stream flow generally coincides with the average amplitude of the meanders. Because of that, it was determined that once the flow entered a flood plain, the surface flow belonged to the larger stream. Thus, all measurements ended at the average amplitude line.

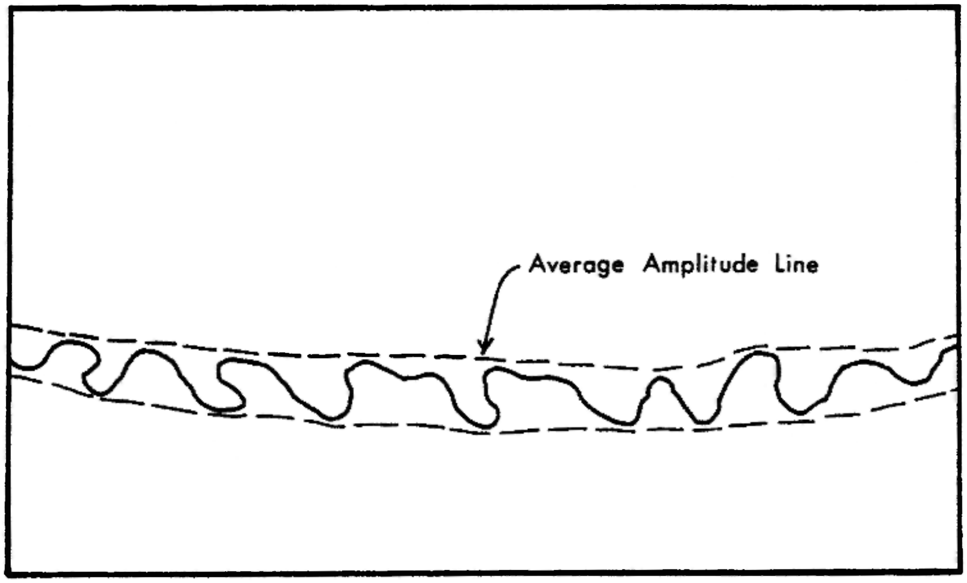


Figure 5:1 Floodplains

After all the streams were located on the mine site, it was noted that there were a number of streams which drained areas upslope from the mine site. Caballo Creek, an intermittent stream which bisects the mine site, is a major drainage for the surrounding area. Duck Nest Creek, Clabaugh Draw, and others although smaller, also drained off-site areas into the Belle Ayr Mine. To determine the orders of such streams would be irrelevant to a project such as this. What is relevant is to know that the off-site watersheds which drain through the Belle

Ayr Mine will be affected by the mining procedure. Any stream which enters a mining site must be restored to its original size, slope, and location in order to assure a hydrologic equilibrium in the upstream watersheds.

Similarly, the mine site may not drain into a single system. This happened in the far northeast corner of the Belle Ayr Mine. A small area did not contribute to the Caballo Creek drainage (see Figure 5:2). Instead, the area contributed to an offsite drainage system. It is necessary to know where this circumstance exists so that same offsite drainage may be restored upon reclamation.

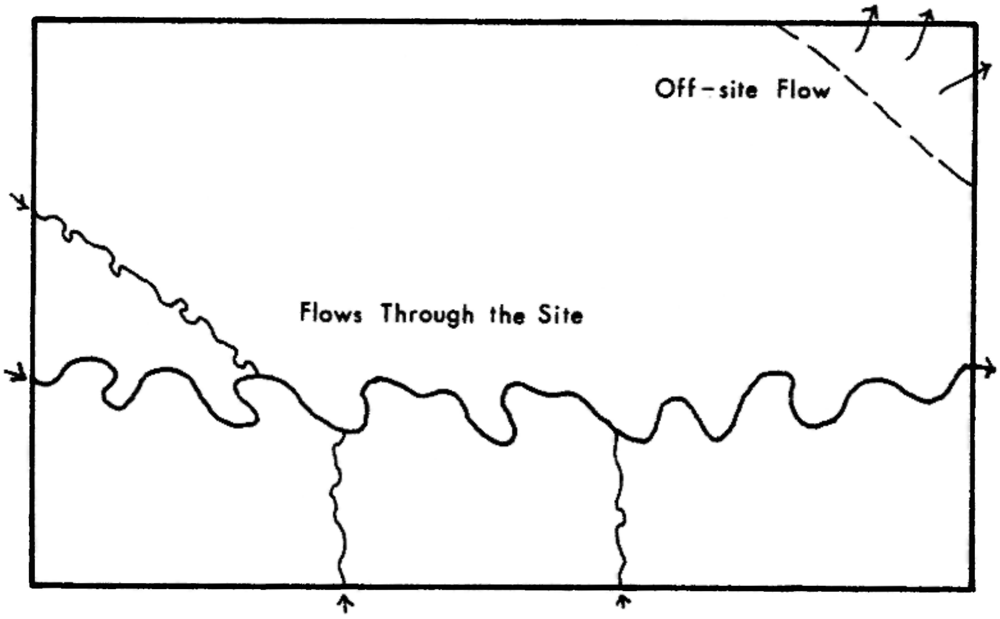


Figure 5:2 Off-site Drainage

Finally, it is not necessary to determine the drainage basins of every stream within the site. Rather, it is only important to determine the drainage basins of streams which flow into the site, the sample watersheds, and the streams within the sample watersheds. More explanation on this is in the description of step three.

Step Three: Locate three sample watersheds

To describe the hydrologic equilibrium of a site, data had to be collected in a systematic manner. The first step in that process was to determine the watersheds to be measured.

It was preferable that all the first order streams within a watershed could be located. It also had to be large enough to have a minimum of a third order stream at its outflow. This provided enough data for a hydrologic characterization. A watershed with a minimum of a third order stream at its outflow will be refered to as a "potential sample watershed".

In some cases, it was not possible to find a potential sample watershed without going off site. For instance, in watersheds one and two in the case study, the data collection had to extend off-site to obtain the necessary measurements. This should be kept to a minimum, however, to reduce the extra amount of base data needed.

The outflow of a potential sample watershed was determined by the existence of the minimum of a third order stream flowing into a larger stream such as Caballo Creek. In the case study, Caballo Creek provided a convenient determinant of potential sample watersheds. It was fairly easy to distinguish sample watersheds by tracing the streams which flowed into Caballo Creek (see Figure 5:3). In some cases, the streams which entered Caballo Creek were larger than a third order stream, still adhering to the requirements of a potential sample watershed stated above.

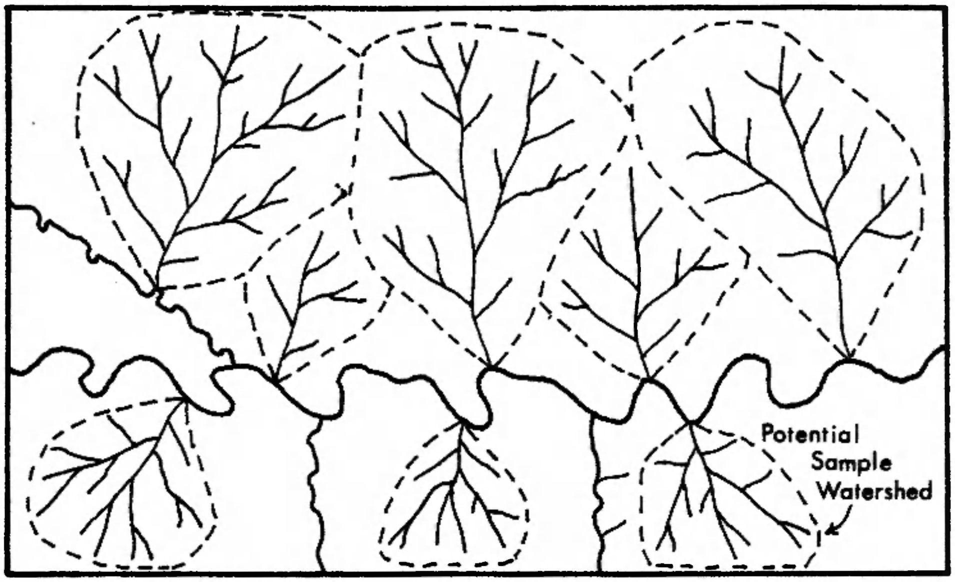


Figure 5:3 Determining Sample Watersheds

At this point, the basins of the potential sample watersheds were determined. This gave an indication of the number of watersheds which must exist upon the watershed reconstruction.

Once all the sample watersheds were located, three were chosen out of the 10 potential sample watersheds. The hydrologic study was based on those three sample watersheds. Three watersheds provided ample amount of data without creating a monumental task of data collection.

It was important to choose watersheds that were created by natural hydrologic conditions. For example, one watershed had a road running through it. This created a watershed different than what would have occurred naturally, so it was not chosen for the data collection. Avoiding all manmade structures was impossible. However, the watersheds chosen had the least number of manmade structures on the site.

As is often the case, some drainage basins are more heavily populated with streams than others. The Belle Ayr Mine site showed this characteristic as well. A conscious effort was made to choose three watersheds which varied in stream population. Watershed one was heavily populated, watershed two had a medium density, and watershed three was lightly populated. In this way, it was anticipated that the data collected would reflect the overall conditions of the site.

Once the three sample watersheds were chosen, the basins of each stream within the watersheds were delineated.

Step Four: Determine the zero order watersheds in the three sample watersheds

The next step in the case study was to determine the zero order drainage basins in the three sample watersheds. The Horton analysis of the "belt of no erosion" was used as the basis for this part of the procedure.

A line was drawn connecting the beginning of each first order stream. Two problems occurred by doing this. First, it did not seem appropriate to connect all the first order streams because the length of the first order streams varied greatly. In some cases, a short stream existed between two long streams (see Figure 5:4).

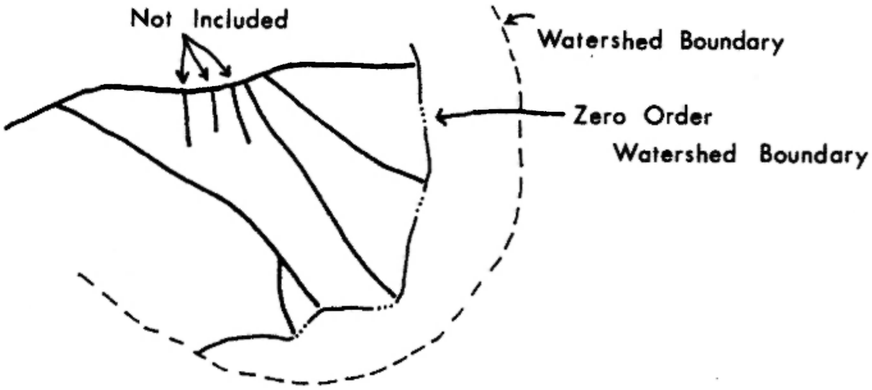


Figure 5:4 Zero Order Watersheds

When this occurred, the corresponding drainage basin was often quite small as well.

If all the streams were connected, it was assumed that the calculation of the zero order watershed would be incorrect. So where abnormalities such as in Figure 5:4 occured, the first order stream was not included in the zero order watershed calulation.

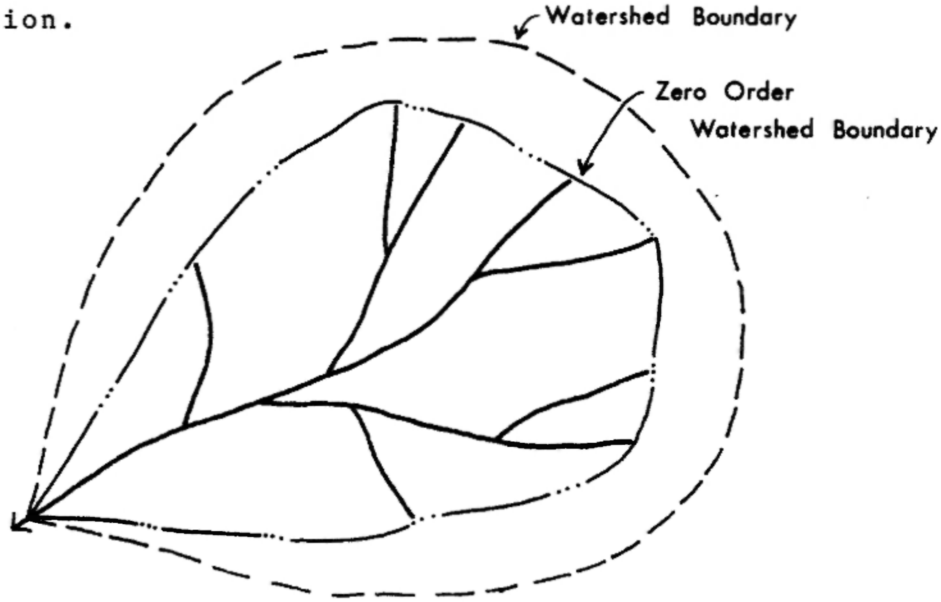


Figure 5:5 Delineating the Zero Order Watershed

The second problem occurred in determining where to end the line connecting the first order streams. In his analysis, Horton

(1945) did not indicate where this should occur. At first it was thought that the zero order watershed should be drawn into the point of the sample watershed outflow (see Figure 5:5). However, considering that the line of the zero order watershed is the point where overland flow changes to channel flow, this seemed inappropriate. Otherwise more first order stream channels would exist closer to the outflow of the sample watershed. Thus it was decided to determine the elevation of the last first order stream. The line delineating the zero order watersheds would then continue along that elevation until the boundary of the sample watershed was met (see Figure 5:6).

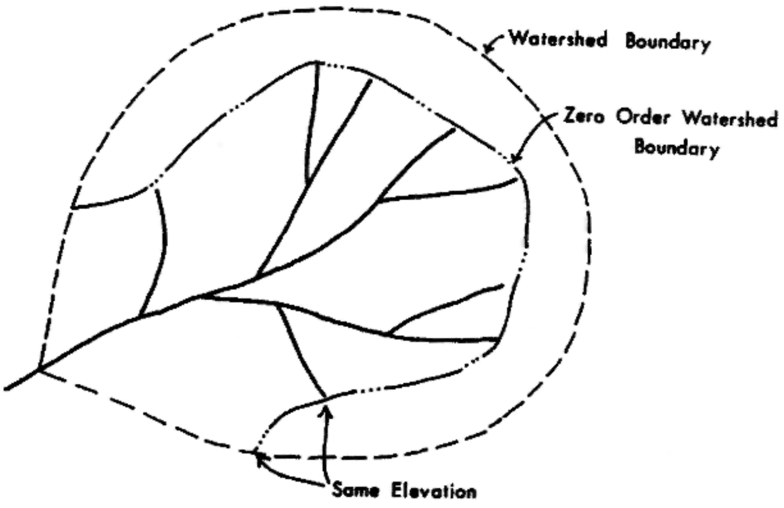


Figure 5:6 Adjusted Zero Order Watershed

Once the area of the zero order watershed was delineated, the area was computed with a planimeter. Then the total area was divided by the number of first order streams which contributed to the area of the zero order watershed. Thus, an average size of the zero order watershed was determined. This was done in all three sample watersheds.

Step Five: Measure the following in each sample watershed

The pre-mined hydrologic characteristics of the site determine the post-mined watershed characteristics. Thus, the data collected in the case study was based on data normally collected in a Horton Analysis.

The first step was to collect the following information on each stream: basin area, stream length, and stream slope. Basin area was determined by using a planimeter to measure watershed boundaries delineated in step three. Stream length was determined by measuring the length of each stream with a map measurer. Stream slope was determined from the contour lines by calculating the relative elevation difference.

It was important to keep accurate records of the measurements. Each stream within an order was numbered. The basin area, stream length, and stream slope were recorded for each stream. An example of the record sheet used is in Chapter six.

Step Six: Calculate the following

The data collected in step five provided the information necessary to calculate the following for each stream order:

average drainage density
average basin area
average stream length
average stream slope

In addition to calculating the averages within the sample watersheds, the averages between the sample watersheds were calculated.

By calculating drainage density, basin area, stream length, stream slope, and stream numbers, each sample watershed could be analyzed to see if they corresponded to the laws of drainage composition. This gave an indication of the stability of the pre-mined drainage network. The drainage network of the Belle Ayr Mine generally corresponded to the laws of drainage composition. Thus, the decisions of base map scale, the method of locating streams, and the method of data collection were appropriate.

Another reason for calculating the list above was to determine the drainage characteristics of the post-mined landscape. Thus, the reconstructed watershed would be designed with the same characteristics.

One problem occured in calculating the drainage density for second order streams and higher. For example, the measured stream length for a second order stream in step four includes only the length of that second order stream. However, the drainage density must have the sum of all the stream lengths within the basin. So the lengths of the first order streams which create the second order stream must be included in the length measurement. All other first order streams which flow into the second order stream must be included as well. The first order length measurements were found by refering to the measurements recorded for the appropriate streams.

Step Seven: Collect data from written sources

In addition to the data collected from the base maps, general information on the Belle Ayr Mine was needed. This was to help determine the relative elevation upon reclamation, the expected infiltration rates, and expected subsidence after reclamation.

To do this, the following data should be collected:

thickness of overburden
thickness of coal seam
mining and reclamation methods
soil infiltration characteristics

The relative elevation of the post-mined site is very important to the design of the reconstructed watershed. In some mining areas, a net gain in elevation results from the volumetric expansion of the overburden. In the Powder River Basin, however, a net loss of elevation occurs because of the low overburden to coal ratio. The loss of elevation ranges from 20 to 100 feet throughout the Powder River Basin (Divis and Tarquin, 1981).

Although it is recognized that the change in elevation will 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 in this study, it was assumed that no drastic change in elevation occurred. The relative post-mined elevation was the same as the relative pre-mined elevation.

Step Eight: Establish the macrotopography of the post-mined landscape

It was first assumed that once the data was collected and the relative elevation of the reclaimed landscape was determined, the macrotopography would be easy to establish. This was found not to be true. To simply choose the high and low points of a 6,000 acre site was quite a task.

To help determine the macrotopography, step nine and step eight of the preliminary procedure were reversed. An overlay of the zero order watershed grid was then placed over the pre-mined topography. Tracing paper was then used to estimate several alternatives of the reconstructed watershed.

It was determined in step two, locate all the streams and their basins, that any stream which flows into a mining site and its watershed can be greatly affected by the mining procedure. Because of that, any stream which flows into the site should be restored to its original size, slope, and location.

The first step in establishing the macrotopography was to locate all the streams that flowed into the site. Once the entry points were located, all streams which exited the site on the pre-mined topography were located.

The next step was to delineate those streams in their pre-mined locations at their original elevations. For example, Caballo Creek, was placed on the site in its original position. In addition, the small area on the northeast corner of the site which flowed offsite was also delineated. Their drainage basins were delineated as well.

Once these streams were delineated, the remaining portions of the site were divided into the same number of sample watersheds that existed before mining. The site was generally divided as equally as possible. The boundaries between the sample watersheds were then delineated.

High and low points within each sample watershed were then located. Care was taken to note the elevation of the area directly adjacent to the Belle Ayr Mine. This adjacent land area gave a good indication of the location of the high points within each sample watershed.

Step Nine: Place a grid the size of the zero order watershed over the entire site

Once the average area of the zero order watershed was established in step six, a grid the size of the average area could be determined.

The basis behind this step was that the zero order watershed is the maximum amount of land exhibiting overland flow without creating a channel. When 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. That channel can be of any order, and can run through, run alongside, or begin at a square.

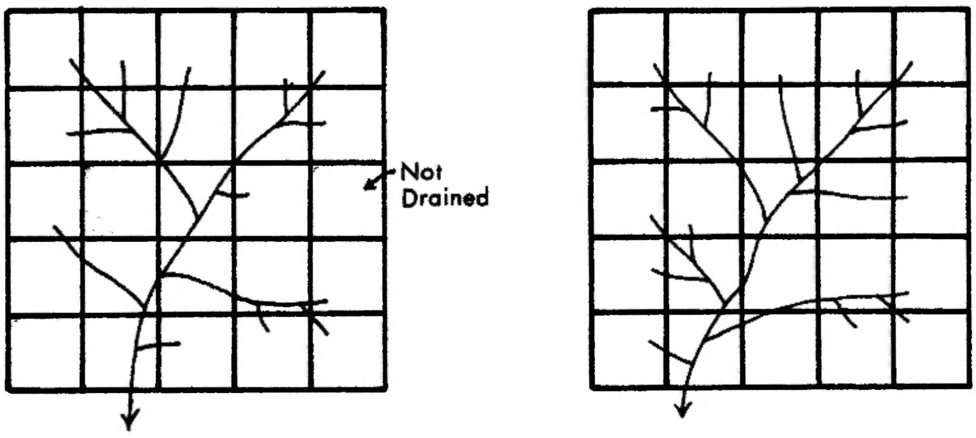
To determine the size of the grid, the square root of the average zero order watershed area in square feet was taken. The result is the length in feet of one side of a square the size of the average zero order watershed. Thus the grid dimensions were determined. An overlay of the grid was placed on the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

Because the Belle Ayr Mine was rectangular, the grid dimensioning was started at the lower left corner of the site. In some cases, odd sized areas were created at the other boundaries of the site. If the odd shaped area was greater than one half the size of the grid dimension, it was considered a complete square. If it was less than one half the size, it was not considered a complete square and was added to an adjacent square.

In the case study, this step was completed before step eight to help establish the macrotopography.

Step Ten: Begin to establish the first order streams

Once the grid had been placed over the site and the boundaries of the sample watersheds had been delineated, the next step was to begin locating the streams within each sample watershed.



Incorrect Correct

Figure 5:7 Establishing Channels from the Zero Order Watershed Grid

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 at a square, flow alongside a square, or flow through a square (see Figure 5:8). Each square must be drained for the site to be designed properly. 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 above. Sometimes it was necessary to move the initial stream channel delineated at the beginning of this step to create a more natural looking drainage network.

In the case study, this part of the process seemed rather intuitive or arbitrary. But upon further examination, it was easy to see that the grid of the zero order area removed much of the guesswork. Still, the number of design possibilities using the grid system are countless. If each square created by the grid is drained, however, the design of the reconstructed watershed should be appropriate.

The result of this step was to create the entire drainage system within a sample watershed. Except for a general consideration of the low and high points in the watershed, stream slope was not taken into consideration at this point in the process. Stream length, drainage density, basin area, and number of streams were also not conisdered. Only the grid of the zero order watershed was considered.

The drainage network created was a dendritic pattern. This was because of the uniform delineation of the sample watershed boundaries and the use of the zero order watershed grid.

Step Eleven: Establish subsequent orders until the site is drained

This step of the procedure was completed in conjunction with step ten. Because streams and their orders are all linked to each other, it is difficult to establish one order at a time. Thus, the entire network of streams was established at the same time.

Step Twelve: Establish the topography

To establish the topography, the average stream slope per order calculated in step six was used. A profile of the longest stream was drawn using the new length and the new elevation. At first, the slope was calculated along the profile of the longest stream using the average slopes from the pre-mined data. Unfortunately this method did not work.

Upon further investigation, it was found that stream order and its corresponding average slope was not relevant. This was because streams of the same order have different slope characteristics. For example, first order streams high in the watershed generally have low slopes. First order streams which flow into a larger streams or "adventitious streams" generally have steeper slopes. Thus, the average slope is just that, an average. The average cannot then be expected to be what actually occurs on an individual basis.

It was then decided that the range of slopes was more accurate than the average. The average slope of the first order streams was 8%, but the range of most of the slopes was from 5% to 10%. The ranges of slopes for the different stream orders are as follows:

First - 5% to 10%
Second - 3% to 7%
Third - 3% to 5%
Fourth - 1% to 4%

The ranges of slopes were then used with the new stream length and the new elevation to create a concave profile. From that, the location of the contours at a five foot interval could be located along the stream channel. This same procedure was then used in determining the slopes for other long stream channels within the watershed. Then the contours were drawn on the plan of the watershed connecting the indicators determined in the stream profiles. The contour interval used on the plan of the reconstructed watershed was 10 feet. This was primarily for ease in calculating and drafting.

It must be stressed that the topography developed in the case study is an estimate because the relative change in elevation remained the same from the pre-mined to the post-mined landscape. Further studies are needed to determine the affect of volumetric expansion or what a net loss has on the post-mined landscape.

Step Thirteen: Repeat steps 3, 4, 5, and 6, for the post-mined topography

Once the topography of three sample watersheds was completed, data collection could occur on three new sample watersheds. The new data was used to analyze the stability of the reconstructed drainage network and to compare it to the pre-mined stream characteristics. The data collected is in Appendix B.

Step Fourteen: Compare the pre-mined data with the post-mined data

The assumption of this study is that if the zero order watershed is used as the basis for design, the hydrologic characteristics of the reconstructed watershed will compare with the pre-mined hydrologic characteristics.

The following is a summary of the pre-mined and the post-mined data:

		Pre-Mined	Post-Mined
Drainage Density (mi/sq mi)		23.00	14.00
Basin Area (sq mi)	First Order	.0052	.0054
	Second Order	.0240	.0211
	Third Order	.1365	.0808
	Fourth Order	.1887	.3285
	Fifth Order	.3429	.5661

		Pre-Mined	Post-Mined
Stream Length (mi)	First Order	.0685	.0640
	Second Order	.1135	.1041
	Third Order	.2443	.2088
	Fourth Order	.4356	.3725
	Fifth Order	.4261	.2581
Stream Slope (%)	First Order	7.3	3.6
	Second Order	4.7	3.0
	Third Order	3.7	2.3
	Fourth Order	2.7	4.0
	Fifth Order	2.2	0.4
Zero Order Watershed Area (sq mi)		.0035	.0034

Figure 5.8 Summary of Data

The basin area and the stream lengths of the post-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, that they too would correspond.

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 drainage density calculations would correspond.

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 last characteristic examined was the zero order watershed. The averages for the pre-mined and the post-mined watersheds were extremely close. Thus, the zero order watershed grid system accurately depicts the zero order watershed.

Step Fifteen: Adjust the post-mined landscape to more closely reflect the pre-mined landscape

It was presumed that some changes must be made to the design of the reconstructed watershed. This was unnecessary in this particular case study. Further studies are suggested to see if this procedure produces similar results.

Future Studies

All research creates a need for further research. Because the design of reconstructed watersheds is new area in the new field of mine reclamation, much additional research is needed.

First, this study should be replicated to test the procedure. The more case studies, the more accurate the conclusions. Also, the case study sites should be expanded to other grographic locations to see if changes are needed in the procedure.

The second area of additional research is needed in determining the 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.

CHAPTER SIX: THE FINAL DESIGN PROCEDURE

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Step 1: Gather base information

a. Determine the appropriate scale of map.
  - Suggested scale 1":500'
  - Suggested contour interval five feet

b. Obtain a topo map at the appropriate scale.

c. Obtain aerial photography at the same scale as the topo map.
  - Distortion must be corrected
  - Stereo photo coverage would provide the best assistance to the procedure

Explanation - The appropriate scale of map depends upon the area's drainage characteristics and the ease of working with a particular scale. A 1":500' scale is suggested for this procedure.

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 the site which have upstream offsite drainages.

c. Locate where streams exit the site and delineate their corresponding drainage basin.

Explanation - It is necessary to locate all the streams within the site. Aerial photographs, especially those providing stereoscopic coverage at the same scale as the base data are necessary to obtain the accuracy needed in this type of study.

If stock ponds occur, draw a line down the center of the pond indicating where the flow line of the stream would occur if the stock pond did not exist.

If a stream seems to disappear by entering a larger stream's floodplain, terminate the stream at the average amplitude meander line (see Figure 6:1). The average amplitude line should be on the base information provided with the mine permit.

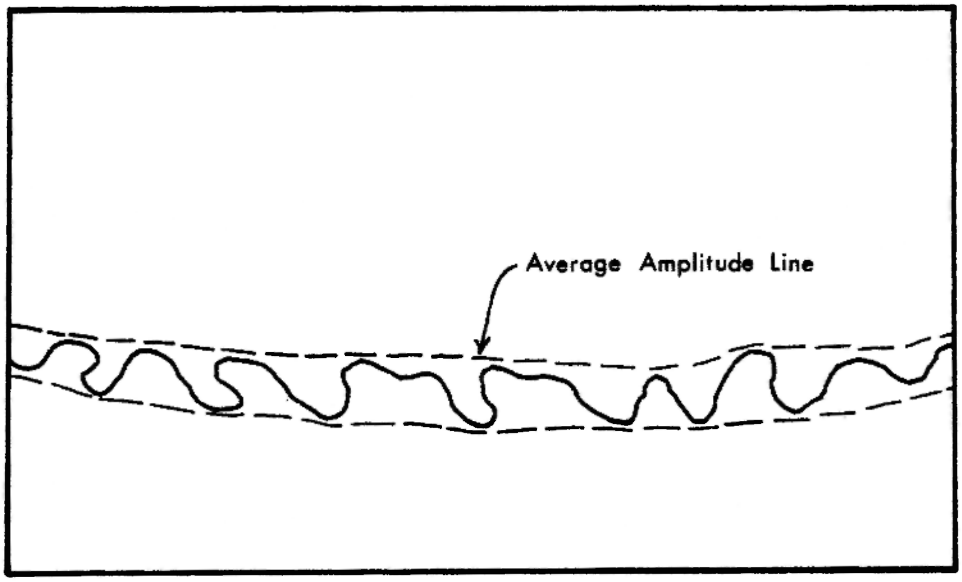

Figure 6:1 Average Amplitude

Some streams provide drainage for offsite areas. Indicate where any such streams enter and exit the site.

Step 3: Delineate the potential sample watersheds

a. Locate all the potential sample watersheds on the site on the mylar overlay.
  - Must be able to locate all the first order streams
  - Must have a minimum of a third order stream at the outflow

b. Delineate the drainage basins for the sample watersheds. Also include the basins for streams which flow into the site.

c. Record the number of sample watersheds existing on the site.

d. Choose three sample watersheds for data collection.

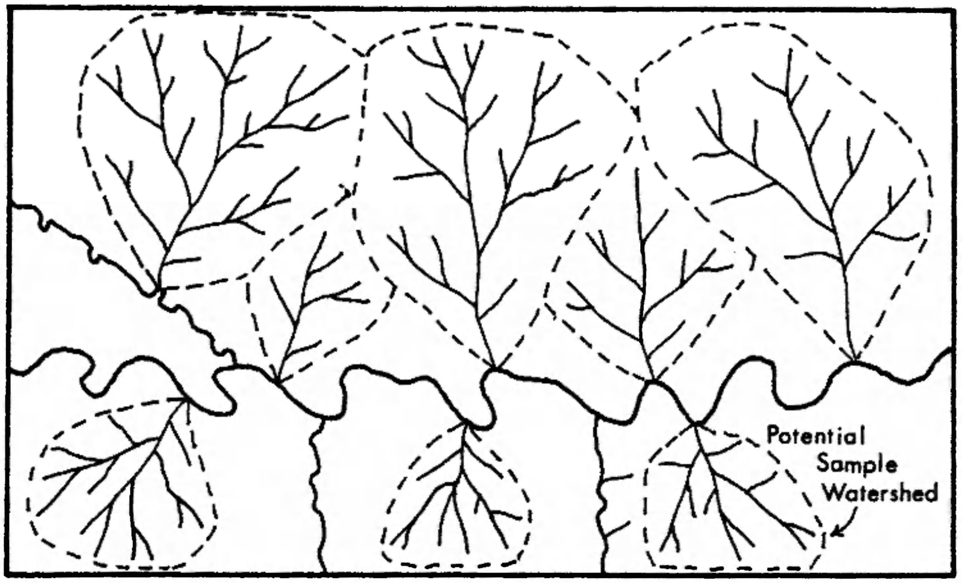

Figure 6:2 Sample Watersheds

Explanation - A sample watershed is one in which all the first order streams can be located and which a minimum of a third order stream is created. In some cases, it may be necessary to extend off-site to include all the first order streams. Keep that to a minimum however, as it increases the amount of base information needed. A sample watershed may be larger than a third order stream at its outflow, but cannot be less than a third order stream.

A convenient place to begin the search for sample watersheds is from a large stream which flows through the site. A minimum of three sample watersheds is needed for accurate data collection.

The number of manmade structures within the three watersheds should be kept to a minimum. This is because the natural hydrologic conditions will have been altered.

Some sample watersheds are more populated with streams than others, Choose three sample watersheds that most closely reflect the average. If this cannot be determined, choose three watersheds one with a high, one with a medium, and one with a low population of streams.

Step 4: Delineate the drainage basins for each stream within the 3 sample watersheds

a. Place tracing paper over the sample watersheds to be measured.

b. Color code the streams by order.

c. Delineate drainage basins for each stream using the same color code as its stream order.

d. Number each stream within each order.

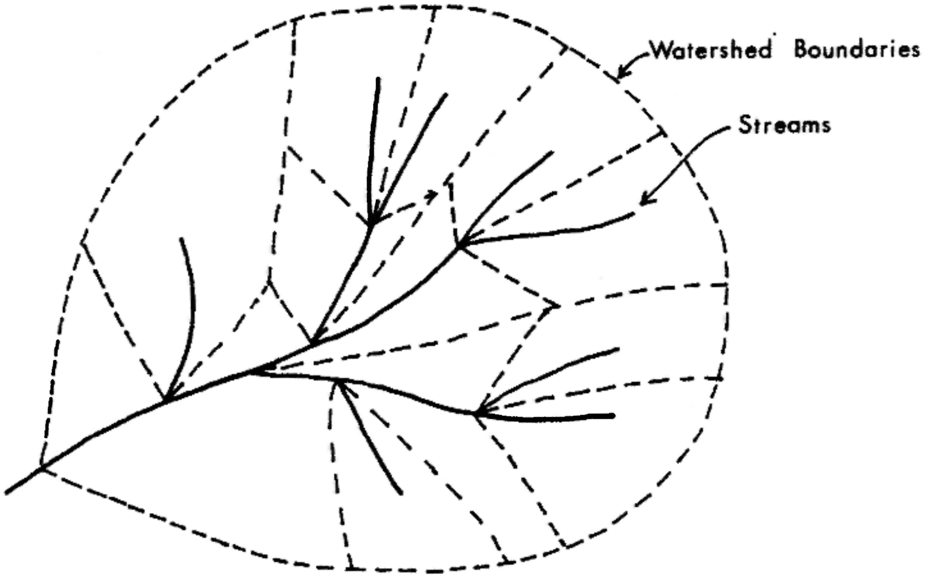

Figure 6:3 Drainage Basins Within a Sample

Explanation - The delineation of the drainage basins for each order prepares the three sample watersheds for data collection. To aid in the collection process, color coding of the streams and their basins by order is suggested. It is also suggested that the drainage basin boundaries be delineated by a colored dashed line.

Step 5: Delineate the area of 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 line of the zero order watershed at that elevation until the boundary of the sample watershed is met.

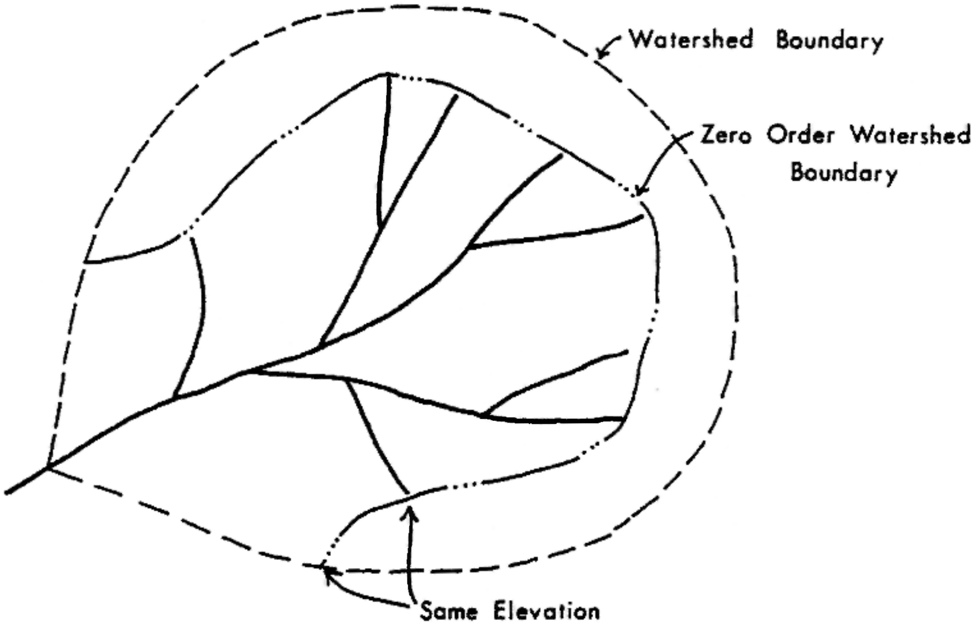

Figure 6:4 The Zero Order Watershed

Explanation - The delineation of the zero order watershed area can be complicated. Not all first order streams will be included in this delineation process. Exclude those first order streams which will create abnormalities in the zero order watershed area. This can happen when a short stream lies between two long first order streams.

Step 6: Measure the following in the three sample watersheds

a. The basin area of each stream and record by stream order.

b. The stream length of each stream with a map measurer and record by stream order.

c. Change in elevation from the beginning to the ending of each stream and record by order.

d. The area of the zero order watershed.

e. The number of first order stream which contributed to the zero order watershed.

Explanation - The measurements listed above are all necessary for determining the hydrologic characteristics of the pre-mined site. Sample record sheets can be found in Appendix B.

Step 7: Calculate the following from the data collected in step #5

a. Calculate for each stream order:

Average drainage density

Average basin area

Average stream length

Average stream slope

Average stream numbers

b. Calculate averages between sample watersheds:

Drainage Density

Basin Area

Stream Length

c. Interpret the data calculated above to see if the pre-mined sample watersheds correspond to the laws of drainage composition. If they do not, choose additional sample watersheds to collect data on.

Explanation - The data listed above is collected in a standard Horton Analysis. This analysis characterizes the state of equilibrium. Determine if the sample watersheds generally correspond to the laws of drainage composition. The following graphs indicate what the average calculations for each order should show if the sample watersheds are in a state of equilibrium.

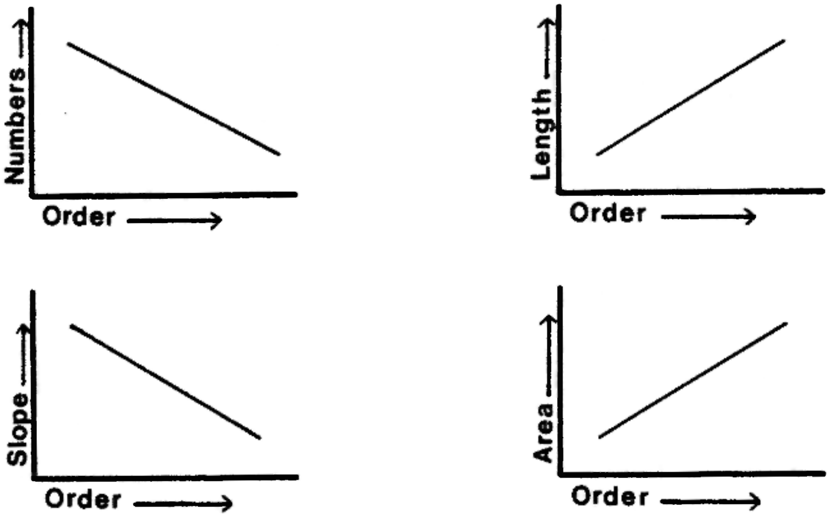

Figure 6:5 Laws of Drainage Composition (Horton, 1945)

The drainage density generally remains consistant through the orders.

Care must be taken to obtain the proper stream length when determining the drainage density. Any stream larger than a first order stream must include the lengths of all the streams within the basin. That total length is what is used in the drainage density calculation.

Step 8: Collect data from written sources

a. Collect the following from data in the mining permit application:

Thickness of overburden
Thickness of coal seam
Mining methods
Reclamation methods
Soil infiltration characteristics

b. Estimate the elevation of the reclaimed surface.

- Determine the amount of volumetric expansion of the overburden.
- Determine if there will be a net loss in elevation.

c. Estimate soil characteristics of overburden and topsoil upon reclamation.

- Determine the potential the amount of overburden mixing from the mining and reclamation methods.
- Determine the potential infiltration characteristics of the reclaimed soils.

Explanation - It is likely that the relative elevation of the reclaimed surface will be higher or lower than the original surface. This depends upon the overburden to coal ratio. Where the ratio is low, the elevation will most likely be lower than the original. Where there is a high overburden to coal ratio, there will likely be a net gain in elevation. This information can be found in the permit application for the mine.

In some cases, volumetric expansion will occur. The swell factor of overburden is difficult to predict. One method is to calculate the volume and swell factor of each rock type. Thus, a crude estimation can be determined. A stripping ratio of 4:1 (overburden thickness : coal thickness) with a swell factor of 25% results in nearly the same post-mined elevation as the pre-mined elevation (Dollhopf, 1983).

The method of mining and reclamation can also affect post-mined topography through the use of equipment and the time of year the site was reclaimed.

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.
  - Take the square root of the average zero order watershed in square feet.

b. On another mylar overlay, place a grid over the site with the dimensions determined above.
   - Place the grid on the site so the fewest incomplete squares will be formed.

Explanation - The basis behind this step is that the zero order watershed is the maximum amount of land which overland flow occurs without creating a channel. Once that area is exceeded, a channel is formed. Thus, if a grid the size of the zero order basin is placed over the site, each square created must be drained by a channel.

Step 10: Establish sample watersheds

a. Establish entry points of all streams which flow into the site. These may be of any order.

b. Establish exit points of all streams which exit the site. These may be of any order.

c. Establish streams which flow into the site from off-site to their original size and location.

d. Establish watershed boundaries of streams which flow into the site and of those streams which flow off-site.

e. Divide the remainder of the site into the same number of sample watersheds that existed in the pre-mined topography. Create watersheds of equal area. The shape need not be similar.

Explanation - To aid in the design of the total watershed, the site is divided into larger basins. The sample watershed delineated in step 3 is used as the basis for delineation.

First all streams entering and exiting the site should be located in their original postions. This is because these streams drain off-site areas. Any change in those streams would disrupt watersheds elsewhere.

Once those streams are located, their drainage basins should be delinated.

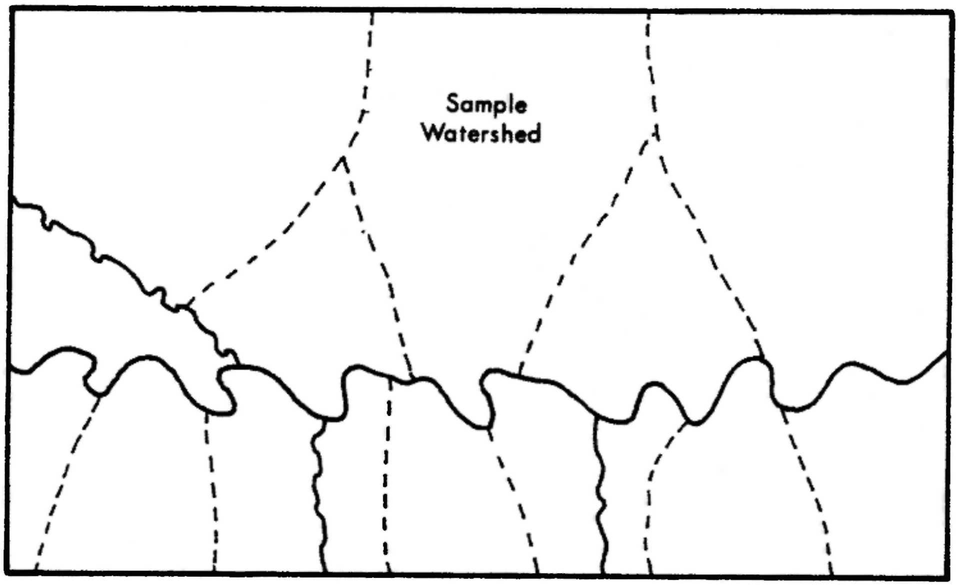

Figure 6:6 Establish Sample Watersheds

From the number of potential sample watersheds recorded in step 3, the remainder of the site can be divided into the same number of sample watersheds. These should be relatively equal in size, yet need not be equal in shape.

Step 11: Establish relative topography in the sample watersheds

Explanation - The relative topography needs to be determined before the watershed can be designed. The elevation of the land adjacent to the site must be taken into consideration so as not to create discrepancies in landform. The adjacent land elevation also gives a good indication of the location of the high and low points in the sample watersheds.

The elevation difference can be estimated from the written data collected and from estimating the original location of any streams which flow into the site.

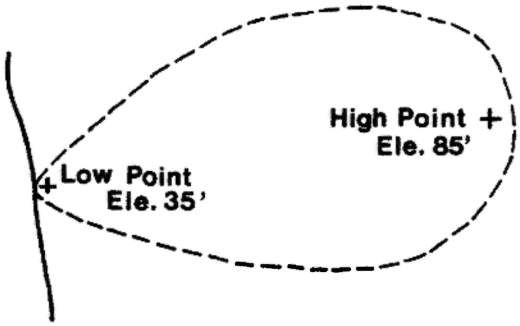

Figure 6:7 Establish Relative Topography

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 watershed.

b. Draw the rest of the 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 at a square, flow alongside a square, 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.

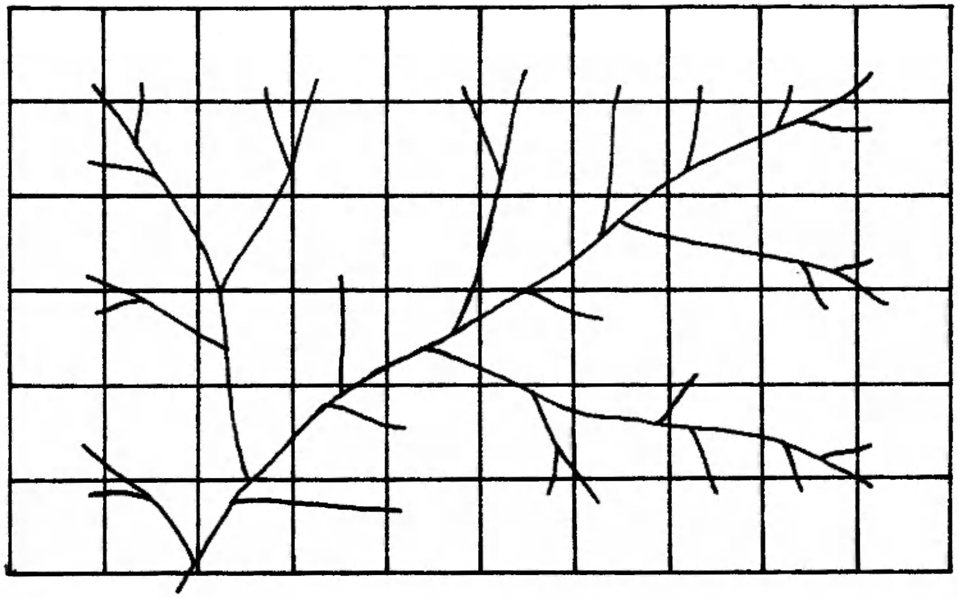

Figure 6:8 Establish Stream Channels

Explanation - The area of the zero order watershed is the basis for the design of the reconstructed watershed. It is the largest area which can have overland flow without creating a stream. When that area is exceeded, a channel is formed. Thus, if a stream drains or runs through a square created by the grid, that square is drained.

Step 13: Establish the topography

a. Draw a profile of the longest stream in the watershed. That stream is most likely the stream which flows from the high point to the low point in the watershed.
   - Measure the length of the stream with a map measurer.
   - Determine the elevation change from step 11.

b. Draw a concave profile.

c. Locate the contour lines at a 10 foot interval.

d. Transfer the location of the contour lines on the plan.

f. Repeat the steps for other long streams within the watershed.

   - Determine the relative elevation from the profile of the longest stream.
   - The high points of these streams are determined by drawing the profiles. The high point must not exceed the highest point in the watershed.

g. Connect the points of equal elevation creating the contour lines. Ridgelines must be created between the stream channels.

Explanation - The average slope calculated earlier cannot be used in this step. averages cannot be used to describe a specific situation. Thus the profile must be drawn using the stream length and the elevation change as givens.

The profiles drawn must be concave. this is because that is the profile of a stream in dynamic equlibrium.

Step 14: Locate 3 new sample watersheds.

a. Choose 3 new sample watersheds on which data will be collected.
   - Use the criteria set forth in step 3 to select the sample watersheds.

b. Repeat step 4 for each of the new sample watersheds.

Explanation - This step is to prepare the new sample watersheds for step 15.

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

a. Determine if the reconstructed watershed corresponds to the laws of drainage composition.

b. If the reconstructed watershed does not correspond to the laws of drainage composition, return to step

12 and alter the reconstructed watershed design.

Explanation - This step is to charcterize the state of equilibrium of the newly designed reconstructed watershed. If the reconstructed watershed is not in a state of equilibrium, it must be redesigned to gain that state of equilibrium.

This step also allows a comparison of the pre-mined and the post-mined landscape.

Step 16: Compare the pre-mined data with the designed post-mined data

a. Compare the following averages calculated for the pre- and post-mined sample watersheds for each order.

Basin area
Stream length
Stream slopes
Drainage density
Area of the zero order watershed

b. If the two sets of data are not similar, return to step 12 and redesign the watershed.

Explanation - The reconstructed watershed must be in a state of equilibrium and have similar characteristics within the range of the pre-mined watershed. If that does not occur, the reconstructed watershed must be redesigned until it is.

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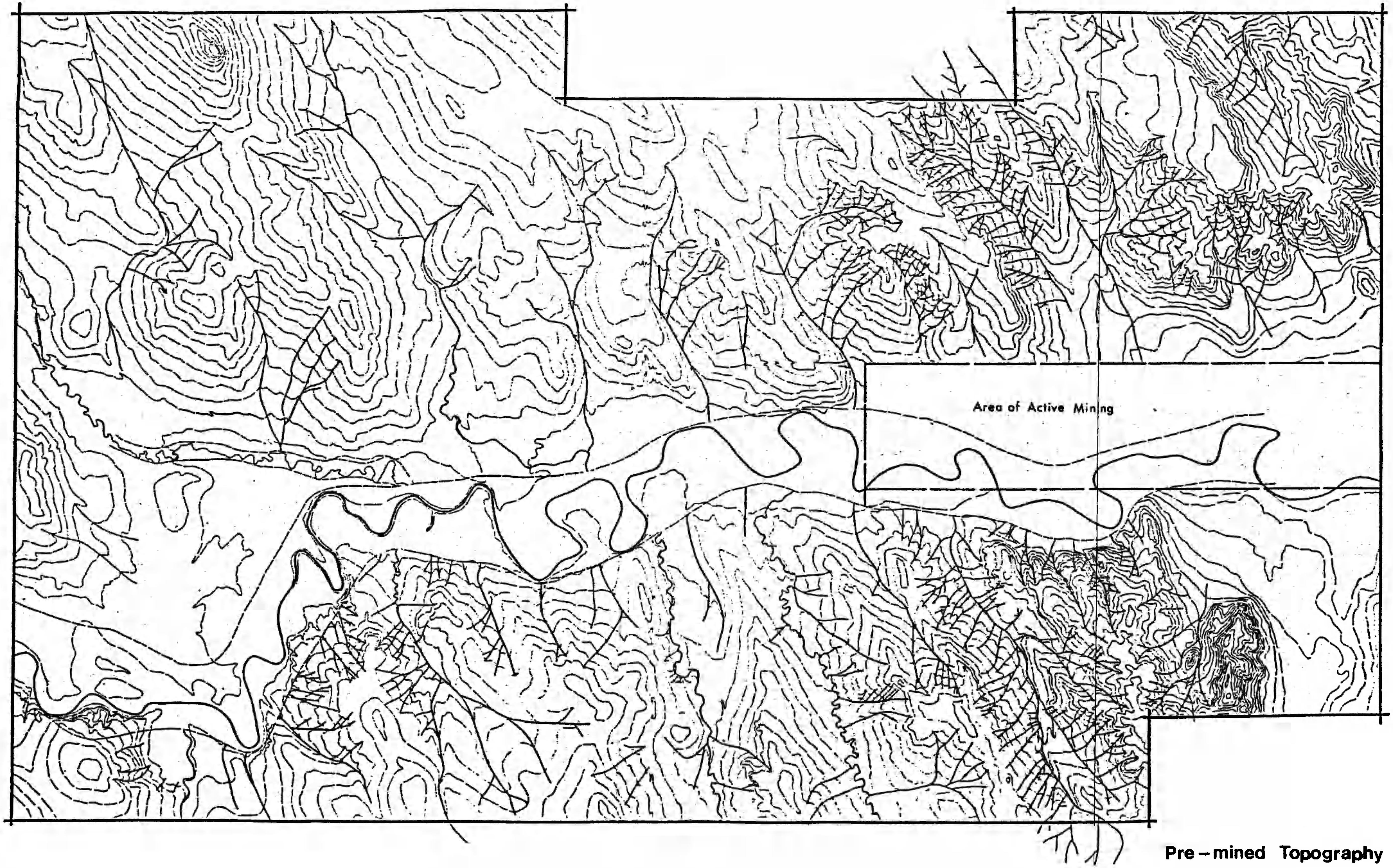
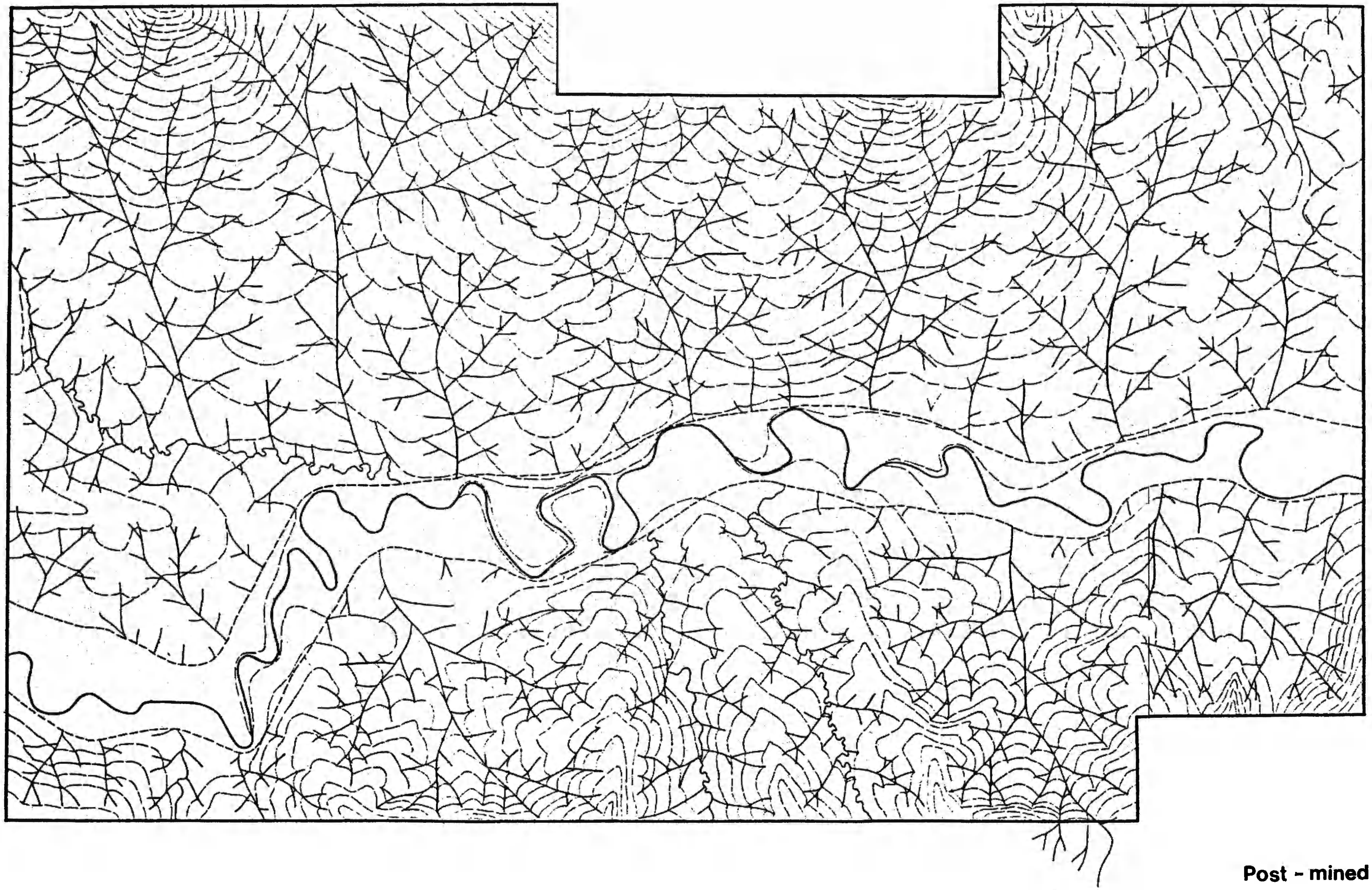
Appendix A

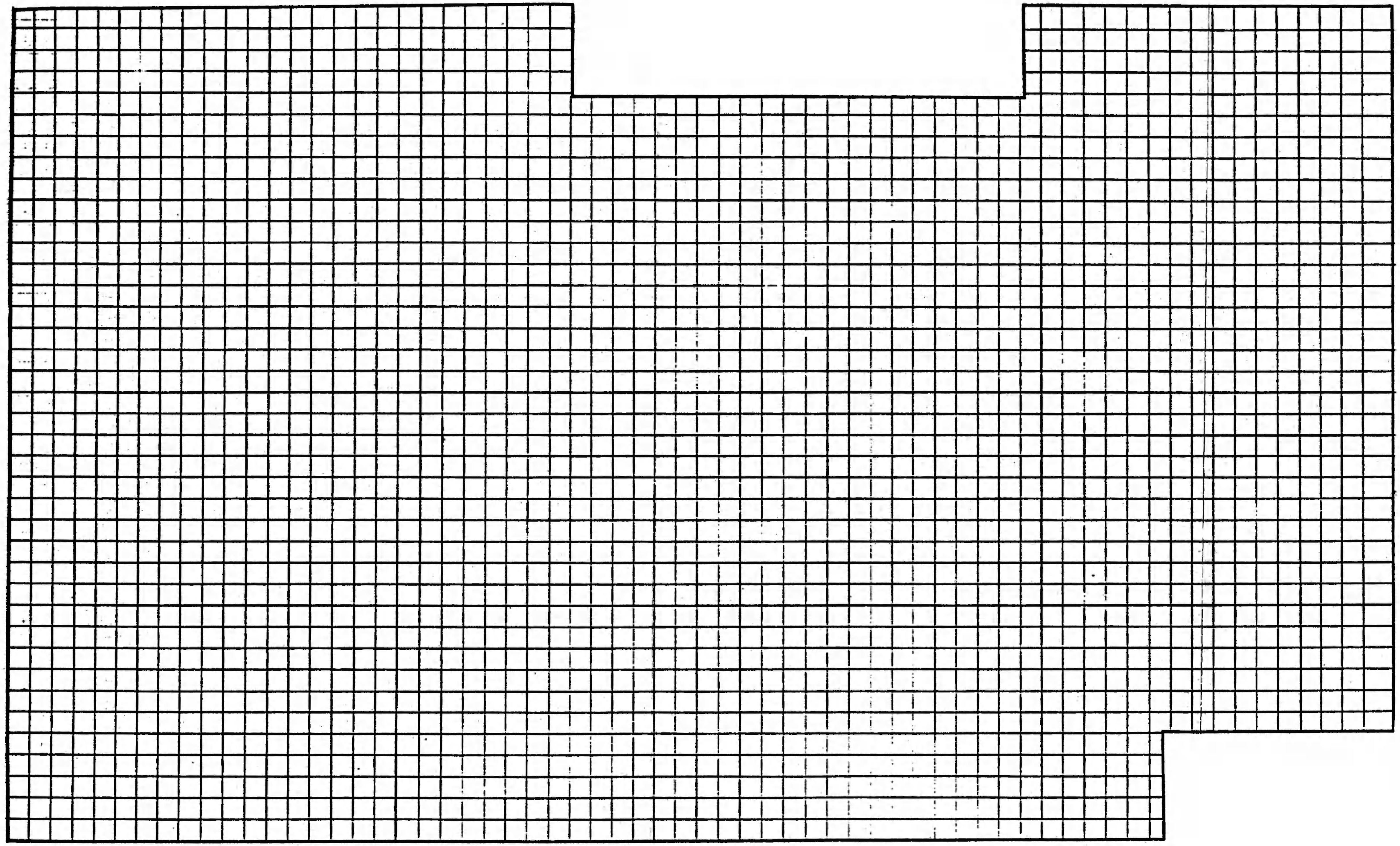
Sample Watershed Maps



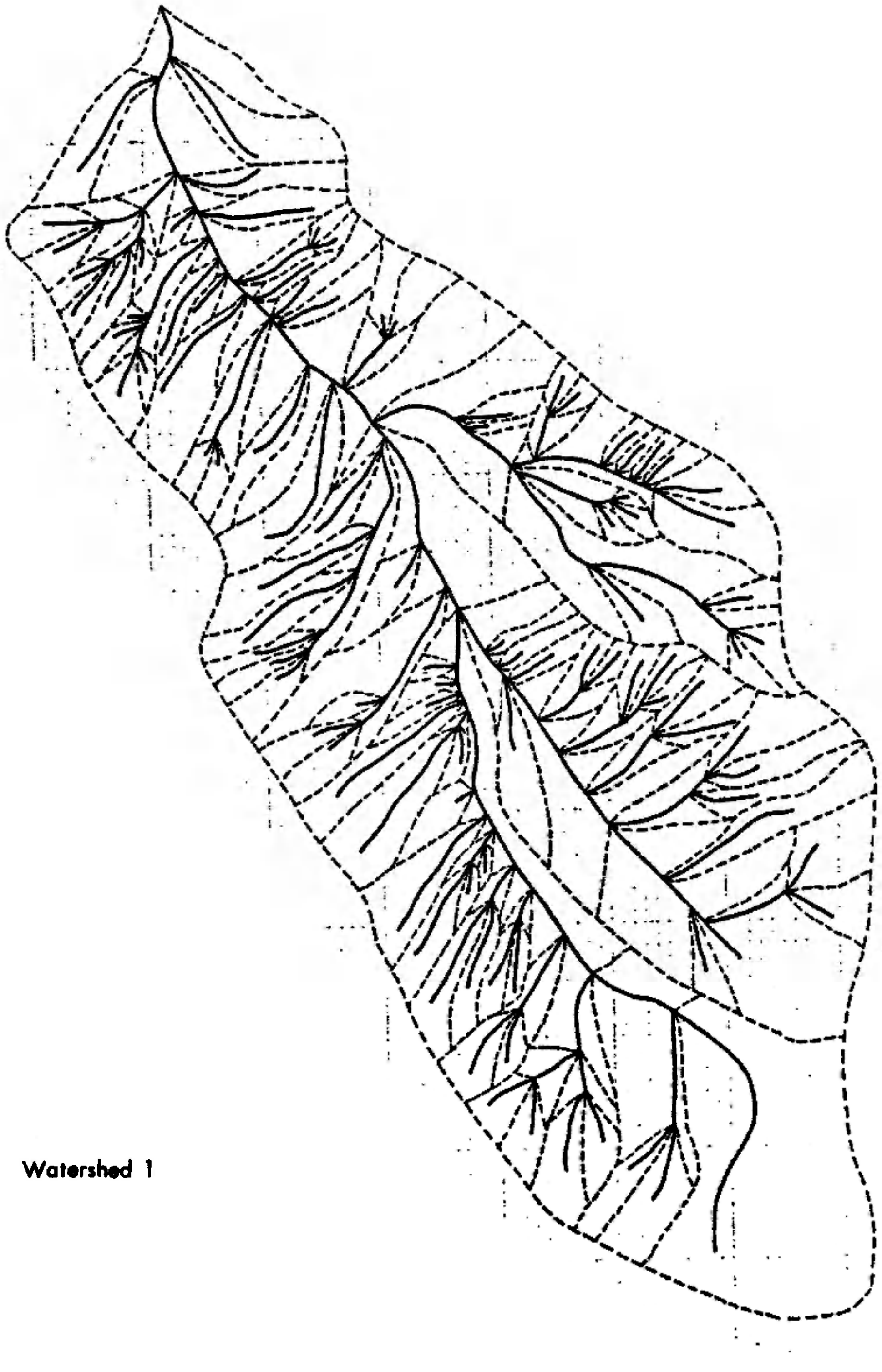
Pre – mined Topography



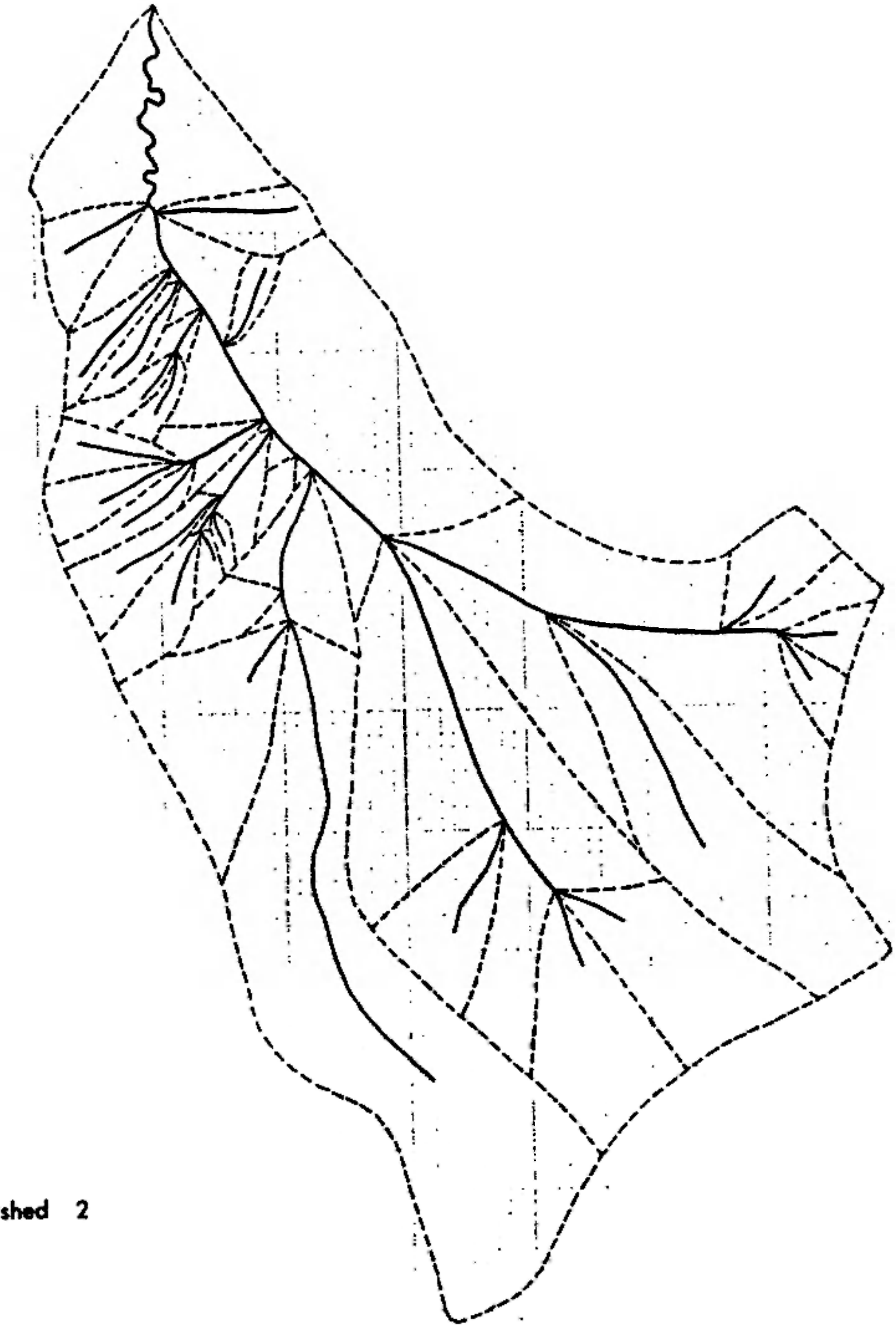
Post - mined Topography



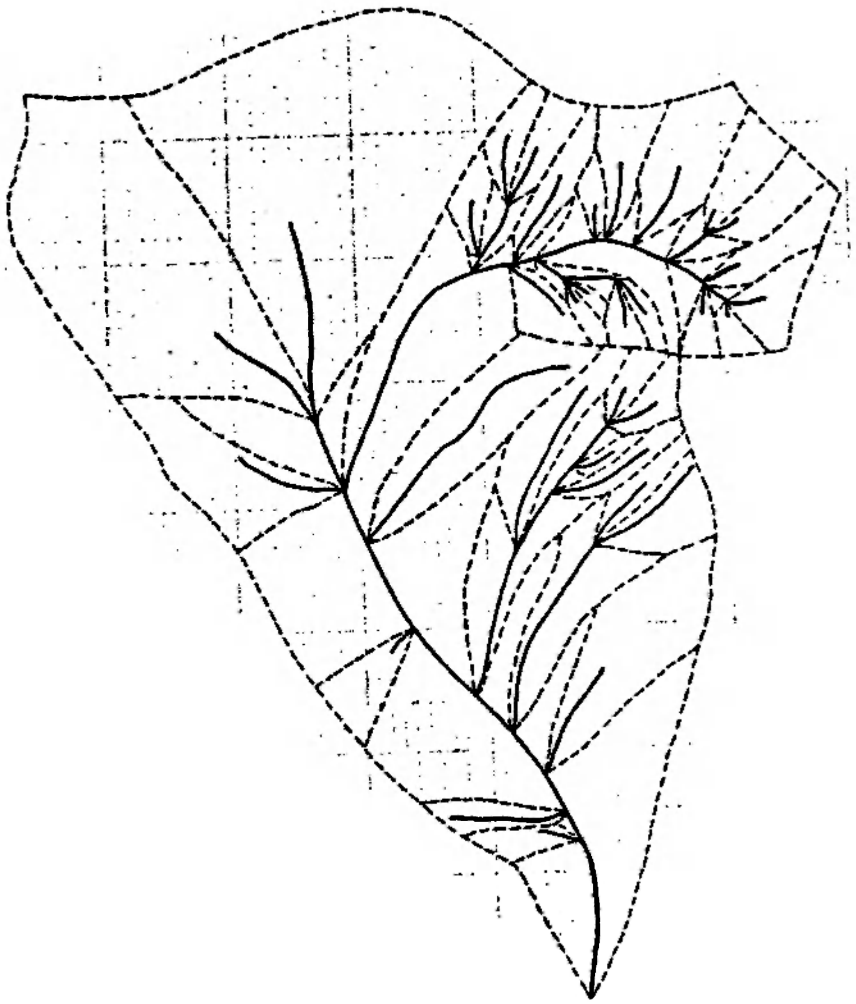
Zero Order Grid



Watershed 1



Watershed 2



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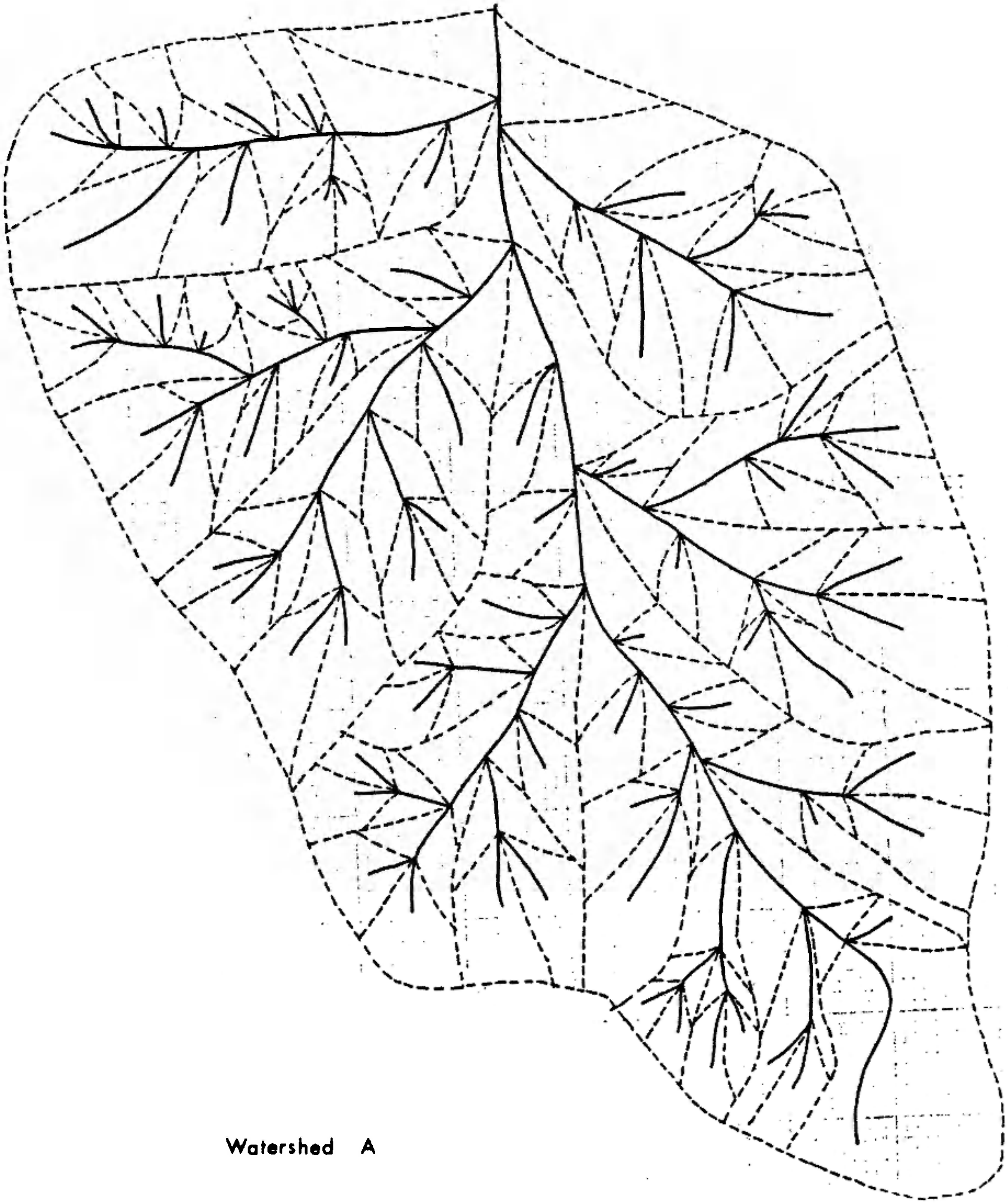
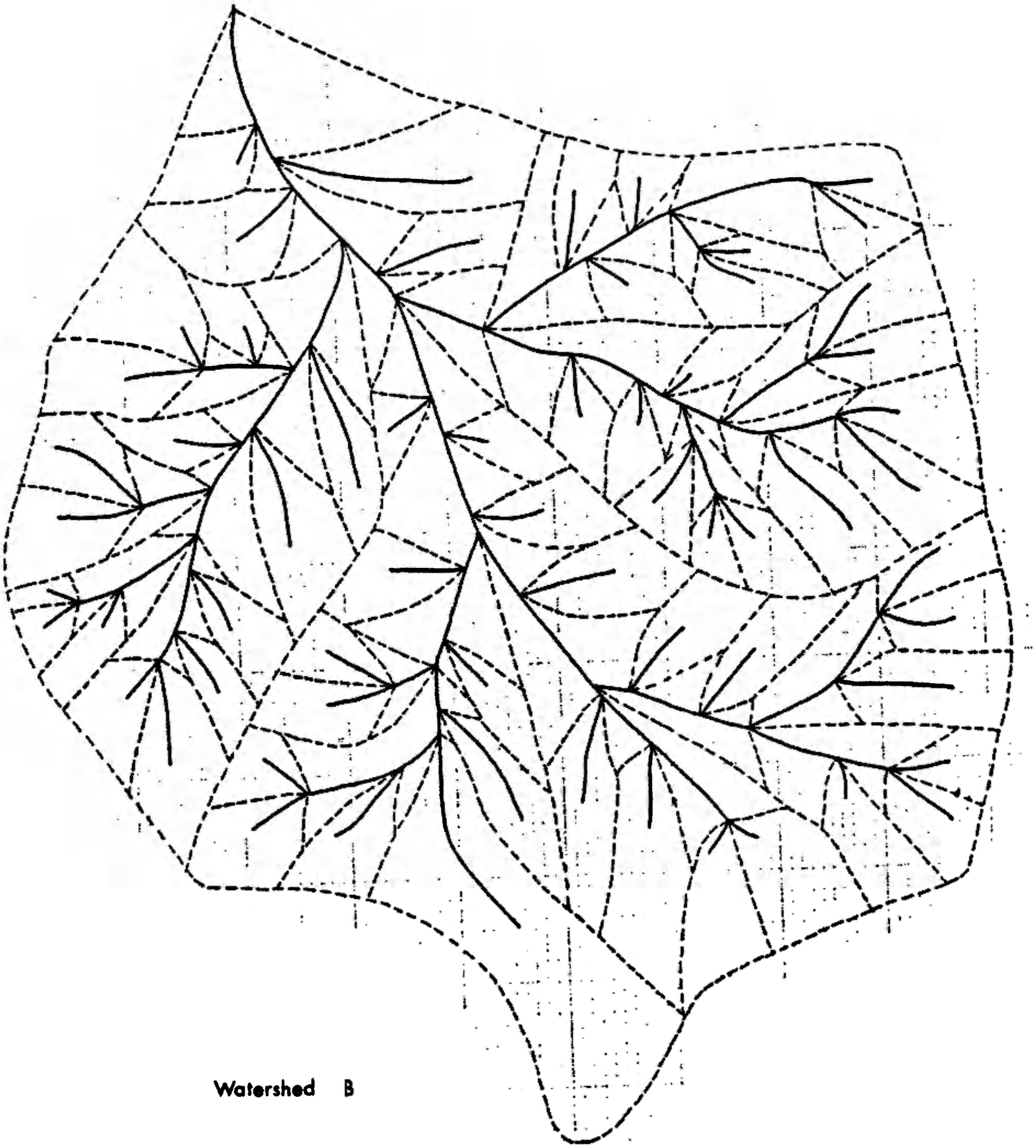
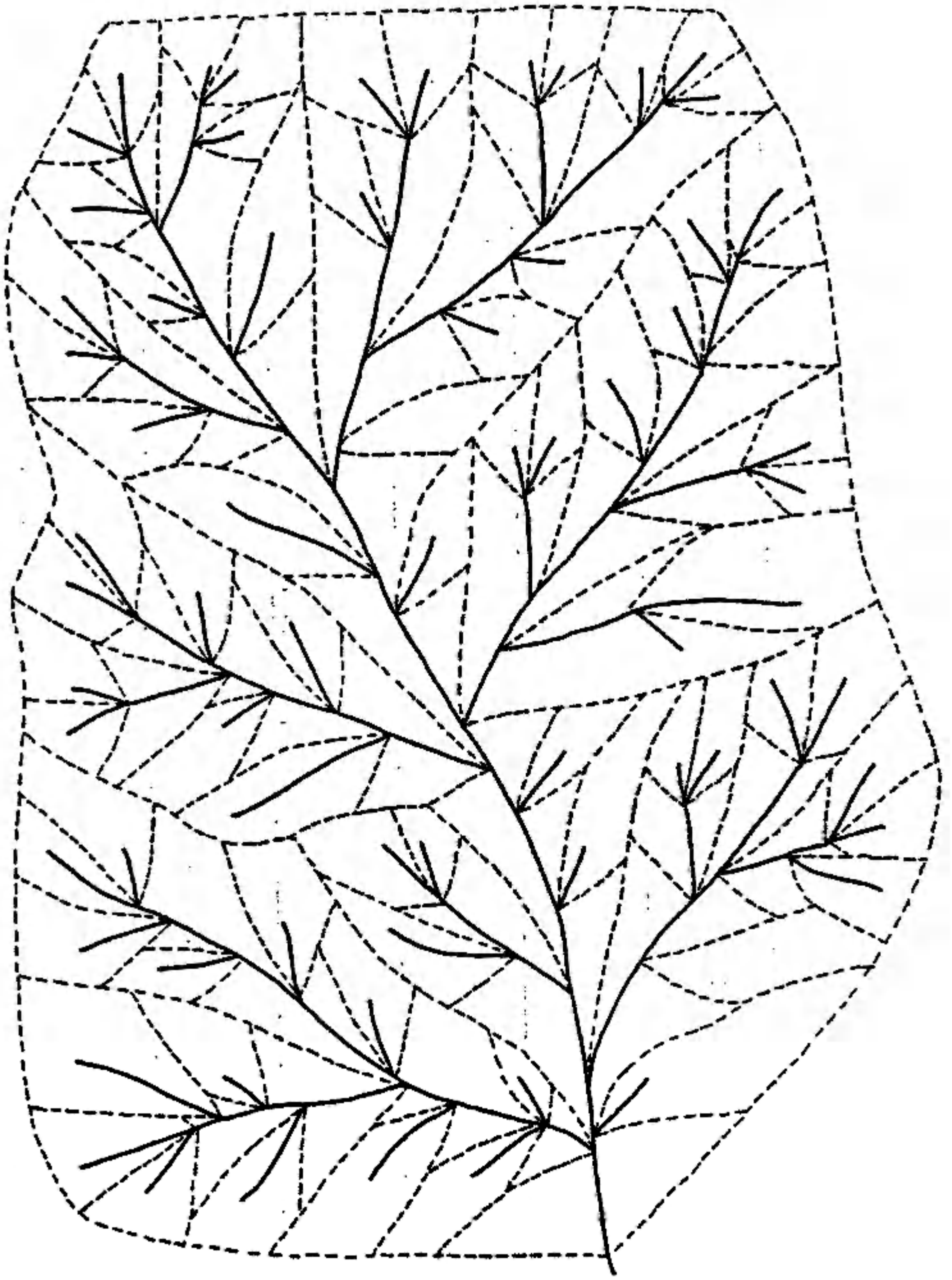


Watershed A



Watershed B



Watershed C

Appendix B

Sample Watershed Data Sheets

Sample Watershed Collection Sheet

Watershed___________

Stream Order_________

Pre-mined__________

Post-mined_________

Stream Number	Planimeter Reading	Area (Sq. Feet)	Area (Sq. Miles)	Length ________ Order (Inches)	Length Lower Orders (Inches)	Total Length (Inches)	Total Length (Feet)	Length (Miles)	Elevation (Feet)	Percent Slope	Drainage Density
Sub Total											
Total											
Average											

Formulas:

Area (sq. feet) = Planimeter Reading * scale squared

Area (sq. miles) = Area (sq. feet) * (5280*5280)

Length (feet) = Length (inches) * scale

Length (miles) = Length (feet) * 5280

% Slope = Elevation (feet) / length (feet)

Drainage Density = Length (miles) / Area (sq. miles)

Pre-mined Watershed Data Summary

Watershed	Order	Average Area (Sq. Miles)	Average Length (Miles)	Average Slope (Percent)	Average Drainage Density
1	0	0.0017			
	1	0.0026	0.0566	10.1	31.66
	2	0.0099	0.0831	6.3	31.94
	3	0.0496	0.1411	3.0	26.64
	4	0.1208	0.1657	2.9	31.25
	5	0.3935	0.4261	2.2	23.24
2	0	0.0049			
	1	0.0076	0.0871	4.9	21.79
	2	0.0446	0.1626	3.0	19.58
	3	0.3429	0.5303	1.3	10.74
3	0	0.0039			
	1	0.0053	0.0618	6.9	23.83
	2	0.0174	0.0947	4.7	30.26
	3	0.0171	0.0616	5.1	33.20
	4	0.2566	0.7055	2.4	14.14
Total	0	0.0035			
	1	0.0052	0.0685	7.3	25.76
	2	0.0240	0.1135	4.7	27.26
	3	0.1365	0.2443	3.7	23.53
	4	0.1887	0.4356	2.7	22.70
	5	0.3429	0.4261	2.2	23.24

Post-mined Watershed Data Summary

Watershed	Order	Average Area (Sq. Miles)	Average Length (Miles)	Average Slope (Percent)	Average Drainage Density
A					
	0	0.0036			
	1	0.0051	0.0605	4.2	13.79
	2	0.0171	0.0768	3.3	14.90
	3	0.0609	0.1823	2.8	15.43
	4	0.1997	0.3456	2.2	16.28
	5	0.5396	0.2131	0.4	15.83
B					
	0	0.0040			
	1	0.0064	0.0700	3.3	12.16
	2	0.0259	0.1153	3.0	13.29
	3	0.1001	0.2301	1.7	13.21
	4	0.2048	0.1563	7.5	13.03
	5	0.5926	0.3030	0.3	12.86
C					
	0	0.0027			
	1	0.0048	0.0614	3.2	13.74
	2	0.0203	0.1202	2.7	14.77
	3	0.0813	0.2139	2.4	14.86
	4	0.5811	0.6155	2.0	14.60
Total					
	0	0.0034			
	1	0.0052	0.0640	3.6	13.23
	2	0.0211	0.1041	3.0	14.32
	3	0.0808	0.2088	2.3	14.40
	4	0.3285	0.3725	4.0	14.64
	5	0.5661	0.2581	0.4	14.35

Sample Watershed Collection Sheet

Watershed_______1___
Stream Order_____1___

Pre-mined_____X___
Post-mined_________

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length Inches	Length Feet	Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	0.96	240000	0.0086	1.25	625	0.1184	45	7.2	13.75
2	0.32	80000	0.0029	0.55	275	0.0521	30	10.9	18.15
3	0.32	80000	0.0029	0.90	450	0.0852	65	14.4	29.70
4	0.07	17500	0.0006	0.10	50	0.0095	15	30.0	15.09
5	0.07	17500	0.0006	0.10	50	0.0095	15	30.0	15.09
6	0.12	30000	0.0011	0.75	375	0.0710	32	8.5	66.00
7	0.23	57500	0.0021	0.50	250	0.0473	20	8.0	22.96
8	2.21	552500	0.0198	0.55	275	0.0521	25	9.1	2.63
9	0.17	42500	0.0015	0.20	100	0.0189	8	8.0	12.42
10	0.22	55000	0.0020	0.10	50	0.0095	8	16.0	4.80
11	0.15	37500	0.0013	0.45	225	0.0426	25	11.1	31.68
12	0.09	22500	0.0008	0.40	200	0.0379	17	8.5	46.93
13	0.09	22500	0.0008	0.40	200	0.0379	22	11.0	46.93
14	0.09	22500	0.0008	0.50	250	0.0473	30	12.0	58.67
15	0.06	15000	0.0005	0.40	200	0.0379	27	13.5	70.40
16	0.07	17500	0.0006	0.50	250	0.0473	30	12.0	75.43
17	0.10	25000	0.0009	0.40	200	0.0379	27	13.5	42.24
18	0.28	70000	0.0025	0.60	300	0.0568	30	10.0	22.63
19	0.53	132500	0.0048	0.60	300	0.0568	33	11.0	11.95
20	0.08	20000	0.0007	0.20	100	0.0189	27	27.0	26.40
21	0.14	35000	0.0013	0.45	225	0.0426	28	12.4	33.94
22	0.18	45000	0.0016	0.25	125	0.0237	13	10.4	14.67
23	0.14	35000	0.0013	0.20	100	0.0189	13	13.0	15.09
24	0.24	60000	0.0022	0.75	375	0.0710	32	8.5	33.00
25	0.12	30000	0.0011	0.20	100	0.0189	22	22.0	17.60
26	0.14	35000	0.0013	0.25	125	0.0237	26	20.8	18.86
27	0.13	32500	0.0012	0.45	225	0.0426	36	16.0	36.55
28	0.09	22500	0.0008	0.30	150	0.0284	40	26.7	35.20
29	0.09	22500	0.0008	0.50	250	0.0473	40	16.0	58.67
30	0.13	32500	0.0012	0.55	275	0.0521	38	13.8	44.68
31	0.13	32500	0.0012	0.50	250	0.0473	35	14.0	40.62
32	0.23	57500	0.0021	0.55	275	0.0521	40	14.5	25.25
33	0.19	47500	0.0017	0.55	275	0.0521	50	18.2	30.57
34	0.40	100000	0.0036	0.60	300	0.0568	30	10.0	15.84
35	0.31	77500	0.0028	0.40	200	0.0379	42	21.0	13.63
36	0.28	70000	0.0025	0.55	275	0.0521	38	13.8	20.74
37	0.54	135000	0.0048	1.40	700	0.1326	52	7.4	27.38
38	0.49	122500	0.0044	0.50	250	0.0473	15	6.0	10.78
39	0.25	62500	0.0022	0.50	250	0.0473	17	6.8	21.12
40	0.90	225000	0.0081	0.50	250	0.0473	10	4.0	5.87
41	0.16	40000	0.0014	0.50	250	0.0473	13	5.2	33.00
42	4.02	1005000	0.0360	2.50	1250	0.2367	40	3.2	6.57
43	0.44	110000	0.0039	0.60	300	0.0568	23	7.7	14.40
44	0.24	60000	0.0022	0.50	250	0.0473	23	9.2	22.00
45	0.22	55000	0.0020	0.40	200	0.0379	15	7.5	19.20
46	0.41	102500	0.0037	0.75	375	0.0710	40	10.7	19.32

47	0.22	55000	0.0020	0.50	250	0.0473	23	9.2	24.00
48	0.19	47500	0.0017	0.50	250	0.0473	16	6.4	27.79
49	0.28	70000	0.0025	0.80	400	0.0758	26	6.5	30.17
50	0.17	42500	0.0015	0.60	300	0.0568	25	8.3	37.27
51	0.24	60000	0.0022	0.90	450	0.0852	27	6.0	39.60
52	0.31	77500	0.0028	1.10	550	0.1042	43	7.8	37.47
53	0.29	72500	0.0026	1.00	500	0.0947	38	7.6	36.41
54	0.53	132500	0.0048	1.40	700	0.1326	52	7.4	27.89
55	0.66	165000	0.0059	1.40	700	0.1326	57	8.1	22.40
56	0.46	115000	0.0041	1.50	750	0.1420	60	8.0	34.43
57	0.19	47500	0.0017	0.40	200	0.0379	15	7.5	22.23
58	0.19	47500	0.0017	0.50	250	0.0473	20	8.0	27.79
59	0.21	52500	0.0019	0.50	250	0.0473	22	8.8	25.14
60	0.24	60000	0.0022	0.40	200	0.0379	25	12.5	17.60
61	0.15	37500	0.0013	0.75	375	0.0710	35	9.3	52.80
62	0.39	97500	0.0035	1.30	650	0.1231	57	8.8	35.20
63	0.47	117500	0.0042	1.25	625	0.1184	47	7.5	28.09
64	0.63	157500	0.0056	2.75	1375	0.2604	55	4.0	46.10
65	0.33	82500	0.0030	1.00	500	0.0947	40	8.0	32.00
66	0.13	32500	0.0012	0.25	125	0.0237	10	8.0	20.31
67	0.11	27500	0.0010	0.25	125	0.0237	10	8.0	24.00
68	0.72	180000	0.0065	1.25	625	0.1184	41	6.6	18.33
69	0.07	17500	0.0006	0.40	200	0.0379	10	5.0	60.34
70	0.23	57500	0.0021	0.50	250	0.0473	20	8.0	22.96
71	0.14	35000	0.0013	0.30	150	0.0284	12	8.0	22.63
72	0.20	50000	0.0018	0.55	275	0.0521	20	7.3	29.04
73	0.13	32500	0.0012	0.60	300	0.0568	24	8.0	48.74
74	0.10	25000	0.0009	0.50	250	0.0473	15	6.0	52.80
75	0.18	45000	0.0016	0.50	250	0.0473	18	7.2	29.33
76	0.23	57500	0.0021	0.55	275	0.0521	17	6.2	25.25
77	0.43	107500	0.0039	1.25	625	0.1184	30	4.8	30.70
Sub Average			0.0030			0.0616		10.7	29.31

Sample Watershed Collection Sheet

Watershed______1_____ Pre-mined_____X___
Stream Order__1,___not associated with zero order basins Post-mined_________

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length Inches	Length Feet	Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	0.06	15000	0.0005	0.20	100	0.0189	10	10.0	35.20
2	0.04	10000	0.0004	0.10	50	0.0095	10	20.0	26.40
3	0.09	22500	0.0008	0.25	125	0.0237	10	8.0	29.33
4	0.10	25000	0.0009	0.25	125	0.0237	20	16.0	26.40
5	0.45	112500	0.0040	0.60	300	0.0568	10	3.3	14.08
6	0.12	30000	0.0011	0.50	250	0.0473	13	5.2	44.00
7	0.12	30000	0.0011	0.60	300	0.0568	22	7.3	52.80
8	0.04	10000	0.0004	0.25	125	0.0237	10	8.0	66.00
9	0.07	17500	0.0006	0.25	125	0.0237	12	9.6	37.71
10	0.22	55000	0.0020	0.20	100	0.0189	12	12.0	9.60
11	0.09	22500	0.0008	0.40	200	0.0379	13	6.5	46.93
12	0.10	25000	0.0009	0.40	200	0.0379	15	7.5	42.24
13	0.12	30000	0.0011	0.20	100	0.0189	9	9.0	17.60
14	0.12	30000	0.0011	0.40	200	0.0379	15	7.5	35.20
15	0.10	25000	0.0009	0.40	200	0.0379	12	6.0	42.24
16	0.28	70000	0.0025	0.50	250	0.0473	12	4.8	18.86
17	0.26	65000	0.0023	1.10	550	0.1042	37	6.7	44.68
18	0.10	25000	0.0009	0.50	250	0.0473	20	8.0	52.80
19	0.19	47500	0.0017	1.00	500	0.0947	36	7.2	55.58
20	0.04	10000	0.0004	0.25	125	0.0237	8	6.4	66.00
21	0.07	17500	0.0006	0.40	200	0.0379	10	5.0	60.34
22	0.06	15000	0.0005	0.30	150	0.0284	10	6.7	52.80
Sub Average			0.0012			0.0390		8.2	39.85
Total Order Average			0.0026			0.0566		10.1	31.66

Sample Watershed Data Collection Sheet

Watershed_______1___
Stream Order___2___

Pre-mined_____X_____
Post-mined__________

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length 2nd Order Streams Inches	Length 1st Order Streams Inches	Total Length Inches	Total Length Feet	Total Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	0.24	60000	0.0022	0.90	0.20	1.10	550	0.1042	32	7.1	48.40
2	0.59	147500	0.0053	0.60	0.30	0.90	450	0.0852	16	5.3	16.11
3	0.29	72500	0.0026	0.45	0.80	1.25	625	0.1184	16	7.1	45.52
4	1.50	375000	0.0135	1.10	3.00	4.10	2050	0.3883	35	6.4	28.86
5	0.45	112500	0.0040	1.00	0.55	1.55	775	0.1468	27	5.4	36.37
6	2.14	535000	0.0192	2.20	1.65	3.85	1925	0.3646	74	6.7	19.00
7	0.33	82500	0.0030	0.55	0.80	1.35	675	0.1278	20	7.3	43.20
8	0.54	135000	0.0048	0.75	1.30	2.05	1025	0.1941	30	8.0	40.09
9	0.60	150000	0.0054	0.90	1.10	2.00	1000	0.1894	25	5.6	35.20
10	1.28	320000	0.0115	1.00	1.55	2.55	1275	0.2415	31	6.2	21.04
11	4.00	1000000	0.0359	2.00	3.40	5.40	2700	0.5114	38	3.8	14.26
12	5.80	1450000	0.0520	1.90	3.60	5.50	2750	0.5208	34	3.6	10.01
13	0.74	185000	0.0066	0.40	1.15	1.55	775	0.1468	7	3.5	22.12
14	0.58	145000	0.0052	0.50	1.00	1.50	750	0.1420	13	5.2	27.31
15	0.61	152500	0.0055	0.90	1.30	2.20	1100	0.2083	25	5.6	38.09
16	0.31	77500	0.0028	0.25	1.20	1.45	725	0.1373	10	8.0	49.39
17	0.64	160000	0.0057	0.40	2.00	2.40	1200	0.2273	15	7.5	39.60
18	0.45	112500	0.0040	0.25	1.50	1.75	875	0.1657	13	10.4	41.07
19	0.77	192500	0.0069	0.25	1.80	2.05	1025	0.1941	2	1.6	28.11
20	1.33	332500	0.0119	1.10	1.30	2.40	1200	0.2273	46	8.4	19.06
21	2.09	522500	0.0187	1.25	5.30	6.55	3275	0.6203	55	8.8	33.09
22	0.54	135000	0.0048	1.10	0.50	1.60	800	0.1515	45	8.2	31.29
23	0.73	182500	0.0065	1.25	1.45	2.70	1350	0.2557	31	5.0	39.06
24	0.57	142500	0.0051	0.55	1.95	2.50	1250	0.2367	19	6.9	46.32
25	0.59	147500	0.0053	0.40	1.05	1.45	725	0.1373	11	5.5	25.95
Average			0.0099	0.0831 (miles)						6.3	31.94

Sample Watershed Data Collection Sheet

Watershed_______1____
Stream Order____3____

Pre-mined______X____
Post-mined__________

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length 3rd Order Streams Inches	Length 1-2 Order Streams Inches	Total Length Inches	Total Length Feet	Total Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	1.81	452500	0.0162	0.20	5.35	5.55	2775	0.5256	5	5.0	32.38
2	2.63	657500	0.0236	0.10	5.40	5.50	2750	0.5208	1	2.0	22.08
3	9.13	2282500	0.0819	2.40	14.85	17.25	8625	1.6335	37	3.1	19.95
4	12.80	3200000	0.1148	4.25	22.50	26.75	13375	2.5331	72	3.4	22.07
5	1.28	320000	0.0115	0.50	3.95	4.45	2225	0.4214	4	1.6	36.71
Average			0.0496	0.1411 (miles)						3.0	26.64

Watershed_______1____
Stream Order____4____

Pre-mined______X____
Post-mined__________

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length 4th Order Streams Inches	Length 1-3 Order Streams Inches	Total Length Inches	Total Length Feet	Total Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	16.06	4015000	0.1440	1.50	11.70	13.20	6600	1.2500	32	4.3	8.68
2	10.88	2720000	0.0976	2.00	53.45	55.45	27725	5.2509	15	1.5	53.82
Average			0.1208	0.1657 (miles)						2.9	31.25

Watershed_______1____
Stream Order____5____

Pre-mined______X____
Post-mined__________

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length 5th Order Streams Inches	Length 1-4 Order Streams Inches	Total Length Inches	Total Length Feet	Total Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	43.88	10970000	0.3935	4.50	92.05	96.55	48275	9.1430	50	2.2	23.24
Average			0.3935	0.4261 (miles)						2.2	23.24

Sample Watershed Collection Sheet

Watershed______2_____
Stream Order____1____

Pre-mined_____X____
Post-mined__________

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length Inches	Length Feet	Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	0.54	135000	0.0048	1.20	600	0.1136	35	5.8	23.47
2	0.21	52500	0.0019	0.75	375	0.0710	28	7.5	37.71
3	0.59	147500	0.0053	0.60	300	0.0568	3	1.0	10.74
4	0.25	62500	0.0022	0.45	225	0.0426	6	2.7	19.01
5	0.27	67500	0.0024	0.50	250	0.0473	6	2.4	19.56
6	2.90	725000	0.0260	2.40	1200	0.2273	25	2.1	8.74
7	1.60	400000	0.0143	0.60	300	0.0568	8	2.7	3.96
8	1.49	372500	0.0134	0.70	350	0.0663	10	2.9	4.96
9	0.89	222500	0.0080	1.00	500	0.0947	20	4.0	11.87
10	6.56	1640000	0.0588	4.10	2050	0.3883	48	2.3	6.60
11	1.56	390000	0.0140	0.50	250	0.0473	13	5.2	3.38
12	0.31	77500	0.0028	0.50	250	0.0473	17	6.8	17.03
13	0.54	135000	0.0048	0.55	275	0.0521	20	7.3	10.76
14	0.51	127500	0.0046	1.05	525	0.0994	30	5.7	21.74
15	0.34	85000	0.0030	1.80	900	0.1705	25	2.8	55.91
16	0.37	92500	0.0033	0.75	375	0.0710	20	5.3	21.41
17	0.35	87500	0.0031	0.80	400	0.0758	20	5.0	24.14
18	0.26	65000	0.0023	1.00	500	0.0947	40	8.0	40.62
19	0.35	87500	0.0031	1.10	550	0.1042	46	8.4	33.19
20	0.50	125000	0.0045	0.75	375	0.0710	16	4.3	15.84
Sub Average			0.0091			0.0999		4.6	19.53

Stream Order__1,___not associated with zero order basins

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length Inches	Length Feet	Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	0.12	30000	0.0011	0.20	100	0.0189	5	5.0	17.60
2	0.07	17500	0.0006	0.25	125	0.0237	8	6.4	37.71
3	0.11	27500	0.0010	0.30	150	0.0284	8	5.3	28.80
4	0.15	37500	0.0013	0.60	300	0.0568	20	6.7	42.24
5	0.21	52500	0.0019	0.55	275	0.0521	20	7.3	27.66
Sub Average			0.0012			0.0360		6.1	30.90
Total Order Average			0.0076			0.0871		4.9	21.79

Sample Watershed Data Collection Sheet

Watershed______2____
Stream Order____2____

Pre-mined_____X_____
Post-mined__________

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length 2nd Order Streams Inches	Length 1st Order Streams Inches	Total Length Inches	Total Length Feet	Total Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	8.75	2187500	0.0785	3.40	3.95	7.35	3675	0.6960	35	2.1	8.87
2	8.65	2162500	0.0776	3.25	2.30	5.55	2775	0.5256	28	1.7	6.78
3	9.15	2287500	0.0821	1.25	5.10	6.35	3175	0.6013	13	2.1	7.33
4	1.53	382500	0.0137	1.10	2.15	3.25	1625	0.3078	15	2.7	22.43
5	1.35	337500	0.0121	0.80	3.35	4.15	2075	0.3930	16	4.0	32.46
6	0.44	110000	0.0039	0.50	1.15	1.65	825	0.1563	13	5.2	39.60
Average			0.0446	0.1626 (miles)						3.0	19.58

Watershed______2____
Stream Order____3____

Pre-mined______X____
Post-mined__________

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length 3rd Order Streams Inches	Length 1-2 Order Streams Inches	Total Length Inches	Total Length Feet	Total Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	38.24	9560000	0.3429	5.60	33.30	38.90	19450	3.6837	37	1.3	10.74
Average			0.3429	0.5303 (miles)						1.3	10.74

Sample Watershed Collection Sheet

Watershed_______3____
Stream Order____1____

Pre-mined_____X____
Post-mined__________

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length Inches	Length Feet	Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	0.23	57500	0.0021	1.00	500	0.0947	42	8.4	45.91
2	0.32	80000	0.0029	0.25	125	0.0237	10	8.0	8.25
3	0.88	220000	0.0079	0.90	450	0.0852	27	6.0	10.80
4	4.12	1030000	0.0369	1.10	550	0.1042	21	3.8	2.82
5	5.30	1325000	0.0475	1.60	800	0.1515	21	2.6	3.19
6	0.19	47500	0.0017	0.50	250	0.0473	20	8.0	27.79
7	0.23	57500	0.0021	0.55	275	0.0521	25	9.1	25.25
8	0.26	65000	0.0023	0.55	275	0.0521	25	9.1	22.34
9	0.32	80000	0.0029	0.80	400	0.0758	32	8.0	26.40
10	0.36	90000	0.0032	0.60	300	0.0568	25	8.3	17.60
11	0.64	160000	0.0057	0.80	400	0.0758	31	7.8	13.20
12	0.33	82500	0.0030	0.25	125	0.0237	8	6.4	8.00
13	0.30	75000	0.0027	0.30	150	0.0284	13	8.7	10.56
14	0.34	85000	0.0030	0.40	200	0.0379	11	5.5	12.42
15	0.30	75000	0.0027	0.30	150	0.0284	10	6.7	10.56
16	0.11	27500	0.0010	0.10	50	0.0095	5	10.0	9.60
17	0.13	32500	0.0012	0.25	125	0.0237	6	4.8	20.31
18	0.09	22500	0.0008	0.40	200	0.0379	10	5.0	46.93
19	0.14	35000	0.0013	0.50	250	0.0473	10	4.0	37.71
20	0.04	10000	0.0004	0.20	100	0.0189	5	5.0	52.80
21	0.08	20000	0.0007	0.20	100	0.0189	5	5.0	26.40
22	0.26	65000	0.0023	0.60	300	0.0568	18	6.0	24.37
23	1.11	277500	0.0100	2.25	1125	0.2131	70	6.2	21.41
24	0.56	140000	0.0050	1.50	750	0.1420	50	6.7	28.29
25	0.16	40000	0.0014	0.40	200	0.0379	15	7.5	26.40
26	0.19	47500	0.0017	0.45	225	0.0426	20	8.9	25.01
27	0.22	55000	0.0020	0.90	450	0.0852	35	7.8	43.20
28	0.20	50000	0.0018	0.65	325	0.0616	25	7.7	34.32
29	0.42	105000	0.0038	1.05	525	0.0994	40	7.6	26.40
30	1.14	285000	0.0102	1.00	500	0.0947	31	6.2	9.26
Sub Average			0.0057			0.0642		6.8	22.58

Stream Order__1,___not associated with zero order basins

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length Inches	Length Feet	Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	0.18	45000	0.0016	0.40	200	0.0379	17	8.5	23.47
2	0.13	32500	0.0012	0.40	200	0.0379	15	7.5	32.49
3	0.08	20000	0.0007	0.40	200	0.0379	15	7.5	52.80
Sub Average			0.0012			0.0379		7.8	36.25
Total Order Average			0.0053			0.0618		6.9	23.83

Sample Watershed Data Collection Sheet

Watershed______3___
Stream Order____2___

Pre-mined____X_____
Post-mined__________

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length 2nd Order Streams Inches	Length 1st Order Streams Inches	Total Length Inches	Total Length Feet	Total Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	9.27	2317500	0.0831	0.60	2.70	3.30	1650	0.3125	6	2.0	3.76
2	0.79	197500	0.0071	0.60	1.60	2.20	1100	0.2083	17	5.7	29.41
3	0.75	187500	0.0067	0.40	0.55	0.95	475	0.0900	10	5.0	13.38
4	1.00	250000	0.0090	0.55	1.05	1.60	800	0.1515	8	2.9	16.90
5	0.28	70000	0.0025	0.50	0.90	1.40	700	0.1326	14	5.6	52.80
6	0.09	22500	0.0008	0.10	0.40	0.50	250	0.0473	4	8.0	58.67
7	1.99	497500	0.0178	2.50	3.65	6.15	3075	0.5824	67	5.4	32.64
8	1.36	340000	0.0122	2.75	1.70	4.45	2225	0.4214	45	3.3	34.55
Average			0.0174	0.0947 (miles)						4.7	30.26

Watershed______3___
Stream Order____3___

Pre-mined______X____
Post-mined__________

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length 3rd Order Streams Inches	Length 1-2 Order Streams Inches	Total Length Inches	Total Length Feet	Total Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	3.36	840000	0.0301	1.10	4.35	5.45	2725	0.5161	18	3.3	17.13
2	0.45	112500	0.0040	0.20	1.90	2.10	1050	0.1989	7	7.0	49.28
Average			0.0171	0.0616 (miles)						5.1	33.20

Watershed______3___
Stream Order____4___

Pre-mined______X____
Post-mined__________

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length 4th Order Streams Inches	Length 1-3 Order Streams Inches	Total Length Inches	Total Length Feet	Total Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	28.61	7152500	0.2566	7.45	30.85	38.30	19150	3.6269	88	2.4	14.14
Average			0.2566	0.7055 (miles)						2.4	14.14

Sample Watershed Collection Sheet

Watershed_______A___
Stream Order_____1___

Pre-mined__________
Post-mined_____X___

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length Inches	Length Feet	Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	0.78	195000	0.0070	0.90	450	0.0852	10	2.2	12.18
2	0.31	77500	0.0028	0.40	200	0.0379	3	1.5	13.63
3	0.32	80000	0.0029	0.50	250	0.0473	8	3.2	16.50
4	0.80	200000	0.0072	1.00	500	0.0947	22	4.4	13.20
5	0.53	132500	0.0048	0.75	375	0.0710	17	4.5	14.94
6	0.72	180000	0.0065	1.20	600	0.1136	20	3.3	17.60
7	0.39	97500	0.0035	0.50	250	0.0473	4	1.6	13.54
8	0.34	85000	0.0030	0.40	200	0.0379	8	4.0	12.42
9	0.41	102500	0.0037	0.80	400	0.0758	14	3.5	20.60
10	0.59	147500	0.0053	0.60	300	0.0568	16	5.3	10.74
11	0.62	155000	0.0056	0.90	450	0.0852	18	4.0	15.33
12	0.53	132500	0.0048	0.45	225	0.0426	5	2.2	8.97
13	0.75	187500	0.0067	0.80	400	0.0758	17	4.3	11.26
14	1.08	270000	0.0097	0.75	375	0.0710	22	5.9	7.33
15	1.24	310000	0.0111	1.05	525	0.0994	25	4.8	8.94
16	0.32	80000	0.0029	0.50	250	0.0473	25	10.0	16.50
17	0.23	57500	0.0021	0.30	150	0.0284	4	2.7	13.77
18	0.29	72500	0.0026	0.25	125	0.0237	4	3.2	9.10
19	0.32	80000	0.0029	0.50	250	0.0473	10	4.0	16.50
20	0.74	185000	0.0066	0.80	400	0.0758	8	2.0	11.42
21	0.90	225000	0.0081	0.80	400	0.0758	20	5.0	9.39
22	0.57	142500	0.0051	0.40	200	0.0379	8	4.0	7.41
23	0.34	85000	0.0030	0.55	275	0.0521	10	3.6	17.08
24	3.81	952500	0.0342	2.10	1050	0.1989	40	3.8	5.82
25	0.43	107500	0.0039	0.75	375	0.0710	23	6.1	18.42
26	0.25	62500	0.0022	0.55	275	0.0521	23	8.4	23.23
27	0.23	57500	0.0021	0.40	200	0.0379	15	7.5	18.37
28	0.38	95000	0.0034	0.75	375	0.0710	40	10.7	20.84
29	0.23	57500	0.0021	0.50	250	0.0473	23	9.2	22.96
30	0.20	50000	0.0018	0.50	250	0.0473	16	6.4	26.40
31	1.27	317500	0.0114	1.10	550	0.1042	38	6.9	9.15
32	0.54	135000	0.0048	0.40	200	0.0379	10	5.0	7.82
33	0.54	135000	0.0048	0.60	300	0.0568	10	3.3	11.73
34	0.59	147500	0.0053	0.60	300	0.0568	15	5.0	10.74
35	0.72	180000	0.0065	0.80	400	0.0758	32	8.0	11.73
36	0.80	200000	0.0072	0.70	350	0.0663	32	9.1	9.24
37	0.70	175000	0.0063	0.50	250	0.0473	10	4.0	7.54
38	0.52	130000	0.0047	0.50	250	0.0473	10	4.0	10.15
39	0.44	110000	0.0039	0.40	200	0.0379	10	5.0	9.60
40	0.27	67500	0.0024	0.55	275	0.0521	10	3.6	21.51
41	0.48	120000	0.0043	0.50	250	0.0473	10	4.0	11.00
42	0.16	40000	0.0014	0.25	125	0.0237	10	8.0	16.50
43	0.50	125000	0.0045	0.75	375	0.0710	15	4.0	15.84
44	0.46	115000	0.0041	0.45	225	0.0426	10	4.4	10.33
45	0.56	140000	0.0050	0.80	400	0.0758	12	3.0	15.09
46	0.62	155000	0.0056	1.00	500	0.0947	15	3.0	17.03

47	0.41	102500	0.0037	0.50	250	0.0473	10	4.0	12.88
48	0.63	157500	0.0056	0.80	400	0.0758	15	3.8	13.41
49	0.84	210000	0.0075	0.55	275	0.0521	12	4.4	6.91
50	0.81	202500	0.0073	0.80	400	0.0758	22	5.5	10.43
51	0.53	132500	0.0048	0.75	375	0.0710	23	6.1	14.94
52	0.41	102500	0.0037	0.60	300	0.0568	23	7.7	15.45
53	0.22	55000	0.0020	0.55	275	0.0521	3	1.1	26.40
54	0.51	127500	0.0046	0.90	450	0.0852	9	2.0	18.64
55	0.93	232500	0.0083	0.90	450	0.0852	10	2.2	10.22
56	0.75	187500	0.0067	0.55	275	0.0521	10	3.6	7.74
57	0.34	85000	0.0030	0.45	225	0.0426	9	4.0	13.98
58	0.31	77500	0.0028	0.50	250	0.0473	8	3.2	17.03
59	0.25	62500	0.0022	0.50	250	0.0473	4	1.6	21.12
60	0.28	70000	0.0025	0.25	125	0.0237	3	2.4	9.43
61	0.24	60000	0.0022	0.40	200	0.0379	5	2.5	17.60
62	0.17	42500	0.0015	0.40	200	0.0379	5	2.5	24.85
63	0.55	137500	0.0049	0.80	400	0.0758	11	2.8	15.36
64	0.31	77500	0.0028	0.75	375	0.0710	4	1.1	25.55
65	0.21	52500	0.0019	0.25	125	0.0237	3	2.4	12.57
66	0.38	95000	0.0034	0.25	125	0.0237	3	2.4	6.95
67	0.60	150000	0.0054	0.80	400	0.0758	12	3.0	14.08
68	1.48	370000	0.0133	1.50	750	0.1420	25	3.3	10.70
69	0.82	205000	0.0074	0.60	300	0.0568	10	3.3	7.73
70	0.28	70000	0.0025	0.40	200	0.0379	6	3.0	15.09
71	0.45	112500	0.0040	0.40	200	0.0379	5	2.5	9.39
72	0.68	170000	0.0061	0.50	250	0.0473	8	3.2	7.76
73	0.39	97500	0.0035	0.40	200	0.0379	5	2.5	10.83
Average			0.0051			0.0605		4.2	13.79

Sample Watershed Data Collection Sheet

Watershed______A____
Stream Order____2____

Pre-mined___________
Post-mined_____X____

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length 2nd Order Streams Inches	Length 1st Order Streams Inches	Total Length Inches	Total Length Feet	Total Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	1.23	307500	0.0110	0.75	0.90	1.65	825	0.1563	10	2.7	14.17
2	1.76	440000	0.0158	0.60	1.75	2.35	1175	0.2225	10	3.3	14.10
3	3.33	832500	0.0299	1.80	2.75	4.55	2275	0.4309	25	2.8	14.43
4	2.24	560000	0.0201	0.50	1.55	2.05	1025	0.1941	10	4.0	9.66
5	1.66	415000	0.0149	0.40	1.55	1.95	975	0.1847	8	4.0	12.40
6	3.12	780000	0.0280	1.40	2.00	3.40	1700	0.3220	30	4.3	11.51
7	4.16	1040000	0.0373	0.50	2.65	3.15	1575	0.2983	10	4.0	8.00
8	1.08	270000	0.0097	1.00	1.30	2.30	1150	0.2178	25	5.0	22.49
9	0.77	192500	0.0069	0.50	1.15	1.65	825	0.1563	7	2.8	22.63
10	0.57	142500	0.0051	0.55	1.00	1.55	775	0.1468	13	4.7	28.72
11	1.99	497500	0.0178	0.50	1.50	2.00	1000	0.1894	8	3.2	10.61
12	1.98	495000	0.0178	0.75	1.50	2.25	1125	0.2131	15	4.0	12.00
13	1.65	412500	0.0148	0.60	1.00	1.60	800	0.1515	10	3.3	10.24
14	0.95	237500	0.0085	0.60	0.95	1.55	775	0.1468	10	3.3	17.23
15	1.14	285000	0.0102	0.75	0.75	1.50	750	0.1420	10	2.7	13.89
16	1.62	405000	0.0145	1.00	1.30	2.30	1150	0.2178	13	2.6	14.99
17	2.15	537500	0.0193	1.00	1.35	2.35	1175	0.2225	12	2.4	11.54
18	1.39	347500	0.0125	0.75	1.35	2.10	1050	0.1989	12	3.2	15.95
19	2.00	500000	0.0179	0.50	1.45	1.95	975	0.1847	5	2.0	10.30
20	2.09	522500	0.0187	1.40	1.70	3.10	1550	0.2936	18	2.6	15.66
21	0.45	112500	0.0040	0.30	0.80	1.10	550	0.1042	4	2.7	25.81
22	0.74	185000	0.0066	0.50	0.50	1.00	500	0.0947	10	4.0	14.27
23	5.80	1450000	0.0520	2.00	4.60	6.60	3300	0.6250	20	2.0	12.02
Average			0.0171	0.0768 (miles)						3.3	14.90

Sample Watershed Data Collection Sheet

Watershed______A____
Stream Order____3____

Pre-mined__________
Post-mined_____X____

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length 3rd Order Streams Inches	Length 1-2 Order Streams Inches	Total Length Inches	Total Length Feet	Total Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	7.03	1757500	0.0630	2.20	6.60	8.80	4400	0.8333	14	1.3	13.22
2	9.14	2285000	0.0820	2.00	9.25	11.25	5625	1.0653	27	2.7	13.00
3	6.27	1567500	0.0562	1.00	5.45	6.45	3225	0.6108	25	5.0	10.86
4	1.82	455000	0.0163	1.20	3.20	4.40	2200	0.4167	35	5.8	25.53
5	8.05	2012500	0.0722	2.50	8.25	10.75	5375	1.0180	45	3.6	14.10
6	7.14	1785000	0.0640	2.00	7.75	9.75	4875	0.9233	20	2.0	14.42
7	6.30	1575000	0.0565	2.90	7.60	10.50	5250	0.9943	20	1.4	17.60
8	8.54	2135000	0.0766	1.60	8.35	9.95	4975	0.9422	7	0.9	12.30
Average			0.0609	0.1823 (miles)						2.8	15.13

Watershed______A____
Stream Order____4____

Pre-mined__________
Post-mined_____X____

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length 4th Order Streams Inches	Length 1-3 Order Streams Inches	Total Length Inches	Total Length Feet	Total Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	29.78	7445000	0.2671	6.10	40.85	46.95	23475	4.4460	89	2.9	16.65
2	14.76	3690000	0.1324	1.20	21.05	22.25	11125	2.1070	9	1.5	15.92
Average			0.1997	0.3456 (miles)						2.2	16.28

Watershed______A____
Stream Order____5____

Pre-mined__________
Post-mined_____X____

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length 5th Order Streams Inches	Length 1-4 Order Streams Inches	Total Length Inches	Total Length Feet	Total Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	60.17	15042500	0.5396	2.25	87.95	90.20	45100	8.5417	5	0.4	15.83
Average			0.5396	0.2131 (miles)						0.4	15.83

Sample Watershed Collection Sheet

Watershed_______B___
Stream Order_____1___

Pre-mined__________
Post-mined_____X___

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length Inches	Length Feet	Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	1.60	400000	0.0143	1.80	900	0.1705	5	0.6	11.88
2	0.62	155000	0.0056	1.00	500	0.0947	5	1.0	17.03
3	0.46	115000	0.0041	1.00	500	0.0947	5	1.0	22.96
4	0.31	77500	0.0028	0.50	250	0.0473	7	2.8	17.03
5	0.40	100000	0.0036	0.55	275	0.0521	5	1.8	14.52
6	0.50	125000	0.0045	0.60	300	0.0568	5	1.7	12.67
7	0.34	85000	0.0030	0.45	225	0.0426	7	3.1	13.98
8	0.62	155000	0.0056	0.50	250	0.0473	7	2.8	8.52
9	0.50	125000	0.0045	0.40	200	0.0379	12	6.0	8.45
10	0.42	105000	0.0038	0.40	200	0.0379	5	2.5	10.06
11	0.80	200000	0.0072	0.95	475	0.0900	5	1.1	12.54
12	0.59	147500	0.0053	0.55	275	0.0521	8	2.9	9.84
13	0.85	212500	0.0076	0.75	375	0.0710	10	2.7	9.32
14	0.90	225000	0.0081	1.00	500	0.0947	20	4.0	11.73
15	1.10	275000	0.0099	1.25	625	0.1184	27	4.3	12.00
16	0.58	145000	0.0052	0.55	275	0.0521	12	4.4	10.01
17	0.27	67500	0.0024	0.40	200	0.0379	10	5.0	15.64
18	0.45	112500	0.0040	0.70	350	0.0663	10	2.9	16.43
19	0.40	100000	0.0036	0.40	200	0.0379	4	2.0	10.56
20	0.49	122500	0.0044	0.55	275	0.0521	10	3.6	11.85
21	0.45	112500	0.0040	0.45	225	0.0426	3	1.3	10.56
22	0.73	182500	0.0065	0.75	375	0.0710	5	1.3	10.85
23	0.88	220000	0.0079	0.90	450	0.0852	11	2.4	10.80
24	0.74	185000	0.0066	0.75	375	0.0710	11	2.9	10.70
25	0.75	187500	0.0067	0.75	375	0.0710	10	2.7	10.56
26	0.57	142500	0.0051	0.80	400	0.0758	9	2.3	14.82
27	0.68	170000	0.0061	0.60	300	0.0568	13	4.3	9.32
28	1.00	250000	0.0090	1.00	500	0.0947	27	5.4	10.56
29	0.41	102500	0.0037	0.60	300	0.0568	15	5.0	15.45
30	0.60	150000	0.0054	0.70	350	0.0663	15	4.3	12.32
31	0.78	195000	0.0070	0.40	200	0.0379	12	6.0	5.42
32	1.08	270000	0.0097	0.30	150	0.0284	9	6.0	2.93
33	0.88	220000	0.0079	0.40	200	0.0379	9	4.5	4.80
34	1.35	337500	0.0121	0.75	375	0.0710	23	6.1	5.87
35	0.85	212500	0.0076	1.00	500	0.0947	30	6.0	12.42
36	0.50	125000	0.0045	0.50	250	0.0473	7	2.8	10.56
37	0.90	225000	0.0081	1.25	625	0.1184	31	5.0	14.67
38	4.15	1037500	0.0372	2.00	1000	0.1894	54	5.4	5.09
39	0.70	175000	0.0063	0.95	475	0.0900	28	5.9	14.33
40	0.77	192500	0.0069	0.60	300	0.0568	14	4.7	8.23
41	0.46	115000	0.0041	0.50	250	0.0473	5	2.0	11.48
42	0.68	170000	0.0061	0.55	275	0.0521	12	4.4	8.54
43	0.42	105000	0.0038	0.75	375	0.0710	12	3.2	18.86
44	0.64	160000	0.0057	0.35	175	0.0331	10	5.7	5.78
45	0.30	75000	0.0027	0.45	225	0.0426	3	1.3	15.84
46	0.70	175000	0.0063	1.50	750	0.1420	15	2.0	22.63

47	1.10	275000	0.0099	1.25	625	0.1184	18	2.9	12.00
48	0.60	150000	0.0054	0.75	375	0.0710	14	3.7	13.20
49	0.46	115000	0.0041	0.75	375	0.0710	17	4.5	17.22
50	1.05	262500	0.0094	1.00	500	0.0947	21	4.2	10.06
51	0.59	147500	0.0053	0.50	250	0.0473	15	6.0	8.95
52	0.38	95000	0.0034	0.40	200	0.0379	10	5.0	11.12
53	0.23	57500	0.0021	0.50	250	0.0473	8	3.2	22.96
54	0.15	37500	0.0013	0.40	200	0.0379	4	2.0	28.16
55	0.83	207500	0.0074	0.90	450	0.0852	8	1.8	11.45
56	0.74	185000	0.0066	1.00	500	0.0947	5	1.0	14.27
57	0.46	115000	0.0041	0.70	350	0.0663	7	2.0	16.07
58	0.55	137500	0.0049	0.75	375	0.0710	8	2.1	14.40
59	1.06	265000	0.0095	0.50	250	0.0473	3	1.2	4.98
60	0.35	87500	0.0031	0.50	250	0.0473	10	4.0	15.09
61	1.01	252500	0.0091	0.60	300	0.0568	5	1.7	6.27
62	0.57	142500	0.0051	0.40	200	0.0379	3	1.5	7.41
Average			0.0064			0.07		3.32	12.16

Sample Watershed Data Collection Sheet

Watershed______B____
Stream Order___2____

Pre-mined__________
Post-mined_____X____

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length 2nd Order Streams Inches	Length 1st Order Streams Inches	Total Length Inches	Total Length Feet	Total Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	2.01	502500	0.0180	1.40	1.15	2.55	1275	0.2415	17	2.4	13.40
2	2.13	532500	0.0191	0.50	0.95	1.45	725	0.1373	7	2.8	7.19
3	2.01	502500	0.0180	1.00	1.50	2.50	1250	0.2367	10	2.0	13.13
4	3.25	812500	0.0291	1.25	3.00	4.25	2125	0.4025	12	1.9	13.81
5	1.62	405000	0.0145	0.90	1.65	2.55	1275	0.2415	20	4.4	16.62
6	3.15	787500	0.0282	1.75	2.40	4.15	2075	0.3930	20	2.3	13.91
7	2.76	690000	0.0248	1.50	1.70	3.20	1600	0.3030	35	4.7	12.24
8	5.11	1277500	0.0458	1.75	2.45	4.20	2100	0.3977	40	4.6	8.68
9	8.02	2005000	0.0719	2.00	5.30	7.30	3650	0.6913	29	2.9	9.61
10	1.35	337500	0.0121	0.50	1.30	1.80	900	0.1705	5	2.0	14.08
11	3.18	795000	0.0285	1.25	3.00	4.25	2125	0.4025	22	3.5	14.11
12	1.31	327500	0.0117	1.75	1.30	3.05	1525	0.2888	20	2.3	24.59
13	1.90	475000	0.0170	0.60	1.90	2.50	1250	0.2367	10	3.3	13.89
14	2.60	650000	0.0233	0.90	1.75	2.65	1325	0.2509	10	2.2	10.76
Average			0.0259	0.1153 (miles)						3.0	13.29

Sample Watershed Data Collection Sheet

Watershed______B___
Stream Order___3___

Pre-mined__________
Post-mined____X___.

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length 3rd Order Streams Inches	Length 1-2 Order Streams Inches	Total Length Inches	Total Length Feet	Total Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	5.70	1425000	0.0511	2.10	5.90	8.00	4000	0.7576	8	0.8	14.82
2	9.69	2422500	0.0869	2.40	10.65	13.05	6525	1.2358	13	1.1	14.22
3	15.54	3885000	0.1394	3.25	13.95	17.20	8600	1.6288	40	2.5	11.69
4	11.42	2855000	0.1024	1.30	9.95	11.25	5625	1.0653	20	3.1	10.40
5	13.47	3367500	0.1208	3.10	15.90	19.00	9500	1.7992	17	1.1	14.90
Average			0.1001	0.2301 (miles)						1.7	13.21

Watershed______B___
Stream Order___4___

Pre-mined__________
Post-mined____X___

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length 4th Order Streams Inches	Length 1-3 Order Streams Inches	Total Length Inches	Total Length Feet	Total Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	15.98	3995000	0.1433	0.90	21.05	21.95	10975	2.0786	0	5.0	14.51
2	29.69	7422500	0.2662	2.40	30.10	32.50	16250	3.0777	0	10.0	11.56
Average			0.2048	0.1563 (miles)						7.5	13.03

Watershed______B___
Stream Order___5___

Pre-mined__________
Post-mined____X___

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length 5th Order Streams Inches	Length 1-4 Order Streams Inches	Total Length Inches	Total Length Feet	Total Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	66.08	16520000	0.5926	3.20	77.25	80.45	40225	7.6184	5	0.3	12.86
Average			0.5926	0.3030 (miles)						0.3	12.86

Sample Watershed Collection Sheet

Watershed_______C___
Stream Order_____1___

Pre-mined__________
Post-mined_____X___

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length Inches	Length Feet	Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	0.64	160000	0.0057	0.80	400	0.0758	7	1.8	13.20
2	0.84	210000	0.0075	1.00	500	0.0947	5	1.0	12.57
3	0.69	172500	0.0062	1.00	500	0.0947	5	1.0	15.30
4	0.45	112500	0.0040	0.60	300	0.0568	8	2.7	14.08
5	0.65	162500	0.0058	1.00	500	0.0947	8	1.6	16.25
6	1.02	255000	0.0091	1.25	625	0.1184	12	1.9	12.94
7	0.55	137500	0.0049	0.50	250	0.0473	5	2.0	9.60
8	0.33	82500	0.0030	0.60	300	0.0568	5	1.7	19.20
9	0.65	162500	0.0058	0.75	375	0.0710	5	1.3	12.18
10	0.44	110000	0.0039	0.90	450	0.0852	7	1.6	21.60
11	0.70	175000	0.0063	0.55	275	0.0521	6	2.2	8.30
12	0.67	167500	0.0060	0.60	300	0.0568	10	3.3	9.46
13	0.51	127500	0.0046	0.60	300	0.0568	10	3.3	12.42
14	0.20	50000	0.0018	1.05	525	0.0994	5	1.0	55.44
15	0.61	152500	0.0055	0.70	350	0.0663	15	4.3	12.12
16	0.60	150000	0.0054	0.55	275	0.0521	5	1.8	9.68
17	0.26	65000	0.0023	0.40	200	0.0379	5	2.5	16.25
18	0.65	162500	0.0058	1.50	750	0.1420	10	1.3	24.37
19	0.57	142500	0.0051	0.50	250	0.0473	9	3.6	9.26
20	0.30	75000	0.0027	0.50	250	0.0473	5	2.0	17.60
21	0.49	122500	0.0044	0.45	225	0.0426	5	2.2	9.70
22	0.52	130000	0.0047	0.60	300	0.0568	8	2.7	12.18
23	0.69	172500	0.0062	0.80	400	0.0758	10	2.5	12.24
24	0.59	147500	0.0053	0.60	300	0.0568	17	5.7	10.74
25	0.62	155000	0.0056	0.90	450	0.0852	15	3.3	15.33
26	0.95	237500	0.0085	1.40	700	0.1326	26	3.7	15.56
27	0.63	157500	0.0056	0.70	350	0.0663	9	2.6	11.73
28	0.48	120000	0.0043	0.40	200	0.0379	9	4.5	8.80
29	0.59	147500	0.0053	0.75	375	0.0710	10	2.7	13.42
30	0.34	85000	0.0030	0.50	250	0.0473	8	3.2	15.53
31	0.48	120000	0.0043	0.60	300	0.0568	19	6.3	13.20
32	0.28	70000	0.0025	0.50	250	0.0473	10	4.0	18.86
33	0.47	117500	0.0042	0.60	300	0.0568	13	4.3	13.48
34	0.30	75000	0.0027	0.30	150	0.0284	6	4.0	10.56
35	0.45	112500	0.0040	0.40	200	0.0379	10	5.0	9.39
36	0.21	52500	0.0019	0.50	250	0.0473	8	3.2	25.14
37	0.96	240000	0.0086	1.25	625	0.1184	15	2.4	13.75
38	0.40	100000	0.0036	0.50	250	0.0473	10	4.0	13.20
39	0.66	165000	0.0059	0.50	250	0.0473	23	9.2	8.00
40	0.55	137500	0.0049	0.60	300	0.0568	18	6.0	11.52
41	0.41	102500	0.0037	0.30	150	0.0284	10	6.7	7.73
42	0.28	70000	0.0025	0.30	150	0.0284	10	6.7	11.31
43	0.43	107500	0.0039	0.55	275	0.0521	15	5.5	13.51
44	0.29	72500	0.0026	0.50	250	0.0473	10	4.0	18.21
45	0.26	65000	0.0023	0.40	200	0.0379	8	4.0	16.25
46	0.46	115000	0.0041	0.40	200	0.0379	5	2.5	9.18

47	0.60	150000	0.0054	0.50	250	0.0473	5	2.0	8.80
48	0.53	132500	0.0048	0.60	300	0.0568	8	2.7	11.95
49	0.57	142500	0.0051	0.70	350	0.0663	12	3.4	12.97
50	0.30	75000	0.0027	0.40	200	0.0379	4	2.0	14.08
51	0.50	125000	0.0045	0.55	275	0.0521	5	1.8	11.62
52	0.69	172500	0.0062	0.75	375	0.0710	12	3.2	11.48
53	0.52	130000	0.0047	0.55	275	0.0521	8	2.9	11.17
54	0.41	102500	0.0037	0.50	250	0.0473	8	3.2	12.88
55	0.58	145000	0.0052	0.50	250	0.0473	8	3.2	9.10
56	0.23	57500	0.0021	0.40	200	0.0379	8	4.0	18.37
57	0.54	135000	0.0048	0.80	400	0.0758	10	2.5	15.64
58	0.46	115000	0.0041	0.55	275	0.0521	7	2.5	12.63
59	0.37	92500	0.0033	0.50	250	0.0473	7	2.8	14.27
60	1.40	350000	0.0126	1.40	700	0.1326	10	1.4	10.56
61	0.43	107500	0.0039	0.50	250	0.0473	4	1.6	12.28
62	0.42	105000	0.0038	0.60	300	0.0568	9	3.0	15.09
63	0.74	185000	0.0066	0.60	300	0.0568	9	3.0	8.56
64	0.32	80000	0.0029	0.30	150	0.0284	8	5.3	9.90
65	0.36	90000	0.0032	0.50	250	0.0473	10	4.0	14.67
66	0.36	90000	0.0032	0.75	375	0.0710	13	3.5	22.00
67	0.67	167500	0.0060	0.75	375	0.0710	13	3.5	11.82
68	0.56	140000	0.0050	0.75	375	0.0710	10	2.7	14.14
69	0.43	107500	0.0039	0.50	250	0.0473	8	3.2	12.28
70	0.46	115000	0.0041	0.90	450	0.0852	10	2.2	20.66
71	0.87	217500	0.0078	0.60	300	0.0568	9	3.0	7.28
72	1.27	317500	0.0114	0.60	300	0.0568	5	1.7	4.99
Average			0.0048			0.0614		3.2	13.74

Sample Watershed Data Collection Sheet

Watershed______C____
Stream Order____2____

Pre-mined__________
Post-mined_____X____

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length 2nd Order Streams Inches	Length 1st Order Streams Inches	Total Length Inches	Total Length Feet	Total Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	4.75	1187500	0.0426	1.75	4.35	6.10	3050	0.5777	9	1.0	13.56
2	4.75	1187500	0.0426	2.60	4.00	6.60	3300	0.6250	27	2.1	14.67
3	2.26	565000	0.0203	1.40	1.65	3.05	1525	0.2888	17	2.4	14.25
4	1.40	350000	0.0126	0.90	0.95	1.85	925	0.1752	10	2.2	13.95
5	2.20	550000	0.0197	1.00	2.00	3.00	1500	0.2841	15	3.0	14.40
6	2.43	607500	0.0218	1.50	1.85	3.35	1675	0.3172	25	3.3	14.56
7	1.43	357500	0.0128	0.60	1.70	2.30	1150	0.2178	10	3.3	16.98
8	1.44	360000	0.0129	1.00	1.20	2.20	1100	0.2083	15	3.0	16.13
9	3.00	750000	0.0269	1.75	1.60	3.35	1675	0.3172	32	3.7	11.79
10	1.34	335000	0.0120	1.00	0.60	1.60	800	0.1515	15	3.0	12.61
11	2.14	535000	0.0192	1.40	1.45	2.85	1425	0.2699	15	2.1	14.06
12	1.25	312500	0.0112	0.80	0.95	1.75	875	0.1657	10	2.5	14.78
13	3.99	997500	0.0358	2.25	3.50	5.75	2875	0.5445	32	2.8	15.22
14	1.39	347500	0.0125	1.10	1.05	2.15	1075	0.2036	14	2.5	16.33
15	2.67	667500	0.0239	1.20	1.90	3.10	1550	0.2936	13	2.2	12.26
16	1.15	287500	0.0103	0.60	0.80	1.40	700	0.1326	10	3.3	12.86
17	1.55	387500	0.0139	1.10	1.50	2.60	1300	0.2462	20	3.6	17.71
18	1.64	410000	0.0147	0.90	2.15	3.05	1525	0.2888	8	1.8	19.64
Average			0.0203	0.1202 (miles)						2.7	14.77

Sample Watershed Data Collection Sheet

Watershed______C___
Stream Order____3____

Pre-mined__________
Post-mined_____X___

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length 3rd Order Streams Inches	Length 1-2 Order Streams Inches	Total Length Inches	Total Length Feet	Total Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	12.16	3040000	0.1090	1.60	15.55	17.15	8575	1.6241	15	1.9	14.89
2	6.98	1745000	0.0626	2.30	7.75	10.05	5025	0.9517	23	2.0	15.20
3	8.09	2022500	0.0725	2.55	9.60	12.15	6075	1.1506	43	3.4	15.86
4	9.80	2450000	0.0879	2.90	9.30	12.20	6100	1.1553	30	2.1	13.15
5	10.74	2685000	0.0963	2.20	12.75	14.95	7475	1.4157	32	2.9	14.70
6	6.64	1660000	0.0595	2.00	7.65	9.65	4825	0.9138	24	2.4	15.35
Average			0.0813	0.2139 (miles)						2.4	14.86

Watershed______C___
Stream Order____4____

Pre-mined__________
Post-mined_____X___

Stream Number	Planimeter Reading	Area Sq. Feet	Area Sq. Miles	Length 4th Order Streams Inches	Length 1-4 Order Streams Inches	Total Length Inches	Total Length Feet	Total Length Miles	Elevation Feet	Percent Slope	Drainage Density
1	64.80	16200000	0.5811	6.50	83.10	89.60	44800	8.4848	65	2.0	14.60
Average			0.5811	0.6155 (miles)						2.0	14.60

WATERSHED RECONSTRUCTION DURING THE REHABILITATION OF SURFACE MINED DISTURBANCES

by

ELIZABETH A. STIEG

B.S., University of Michigan, 1979

AN ABSTRACT OF A MASTER'S THESIS

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MASTER OF LANDSCAPE ARCHITECTURE

Department of Landscape Architecture

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Manhattan, Kansas

1985

ABSTRACT

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In the past few years, the United States has increased its surface coal production to help alleviate the diminishing supply of other fuel sources. The increase in coal production has created conflicts because of the destructive nature of surface mining.

Water pollution caused by erosion is a major concern of any surface mining operation. Past studies indicate that erosion can be minimized if the time it takes watersheds to reach their dynamic equilibrium is reduced. Therefore, recent attention is being given to the reduction of erosion through the reconstruction of watersheds during rehabilitation.

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. Then, the procedure was tested through a case study using the Belle Ayr Coal Mine near Gillette, Wyoming. The preliminary procedure was then revised to accommodate the findings.

The results of the case study show that the reconstructed watersheds closely resemble the pre-mined drainage composition if the design procedure is followed. Thus, through this procedure, reconstructed watersheds can be designed. 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.