EROSION AND SEDIMENTATION CONTROL
IN STRIP MINING OPERATIONS

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PREFACE

In this era of increased awareness of both energy and environmental constraints, coal strip mining has emerged as a highly controversial subject. Strip mining, though considerably more economical than underground mining, disturbs the soil cover and can lead to increased erosion and sedimentation problems. Society has four alternatives to deal with the associated environmental degradation: 1) to accept the damage and view the strip mining areas as "national sacrifice areas"; 2) to circumvent the problem by not mining at all; 3) to integrate preventive measures with the mining process, and 4) to carry out remedial measures after the area has been mined. The political and socio-economic realities rule out the first two alternatives. No area can be declared of national sacrifice nor can the goal of self-sufficiency in energy be abandoned. In planning strip mining operations, it is apparent that the choice will have to be made between the remaining two alternatives or a viable combination of both. The decision making process needs to be based on an assessment of the environmental consequences during the interim period between the first act of disturbing the area and the final restoration of the land. It is possible to assess these consequences in terms of erosion and sedimentation by adapting existing knowledge developed in related disciplines.

This report is directed towards this aim. It comprises a state-of-the-art presentation of the assessment of erosion from disturbed lands, measurement of sediment load in streams for use as baseline data or continuous monitoring, and the preventive measures associated with sediment control. A summary of legislation regulating the environmental impact of strip mining operations is included. It is hoped that research towards a better understanding of the processes of erosion and sedimentation from strip mined areas will continue and improved preventive and remedial measures will be developed.

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Chapter I

INTRODUCTION

This report explores the present state of knowledge concerning the phenomena of erosion and sedimentation in strip-mined watersheds. The importance of coal in meeting the energy demands of the nation is recognized, and consequently the technology of coal strip mining, its causes and effects, are analyzed in particular.

This introductory chapter is intended to provide a general background to the problem. It presents a brief review of coal mining in the United States, as well as an assessment of the environmental impact of strip mining. Chapter II deals with sediment yield from strip mining, while Chapter III presents a review of the equipment and techniques for the measurement of sediment. Chapter IV is a summary of the current surface mining legislation, both state and federal. Specifically, the regulations that pertain to erosion and sedimentation control are emphasized. A comprehensive table summary enables an up-to-date overview of the legal aspects of strip mining reclamation.

Chapter V summarizes the present knowledge of erosion and sedimentation control in surface mining. The control of erosion during and immediately after mining is closely connected to the mining operation. Accordingly, surface mining methods and equipment are surveyed for the sake of completeness and consistency with the remainder of the Chapter.

1.1.0. Coal Mining in the United States

Energy is a fundamental input to the well-being of society. In the U.S. in particular, energy consumption has undergone a considerable increase over the last few decades. The utilization of the various energy sources has been largely determined by the availability of the particular resource in a given time and space framework.

Wood accounted for most of the energy available for use in the nineteenth century. In the beginning of the twentieth century coal emerged as a major source of energy, and subsequent decades were to see a switch to gas and petroleum products. This trend is now being jeopardized by the recent international developments regarding oil trade, and nations are increasingly turning back to coal as an alternative energy source. Among other energy sources, coal stands in a position of privilege due to its relatively low cost and the already existing technology for its extraction. Its increased marketability has brought forth a revived interest in coal mining that has manifested itself in a recent period of steady growth for the coal industry.

1.1.1. Total Coal Resources

Coal-bearing rocks are widely distributed and abundant in most regions of the United States. These coal-bearing rocks range in thickness from a few hundred feet to somewhat more than 10,000 ft. Most coal-bearing rocks are less than 3000 ft thick. Coal beds are distributed irregularly throughout the sequences of coal-bearing rocks.

In most coal-field areas the coal-bearing rocks and the enclosed coal beds lie in structural basins, the largest of which are broad and shallow. In the huge Appalachian basin, for example, the bulk of the coal lies within 3000 ft of the ground surface. In the Eastern and Western Interior basins, the coal is generally less than 2000 ft below the surface. In the vast Northern Great Plains region, the bulk of the coal is less than 1500 ft below the surface.

Other coal basins, particularly those in the Rocky Mountain region and in the Pacific Northwest, are characterized by steep dips and narrow marginal belts of accessible coal. The geologic relations of many large, shallow basins and a few very deep ones accounts for the fact that the United States coal resources are concentrated in the shallow overburden categories, and are successively smaller in the deeper overburden categories.

The estimated total remaining coal resources of the United States as of January 1, 1967, total 3210 billion tons, distributed in three major categories, as shown in Table I-1.

Table 1.1. Estimated total remaining coal resources in the United States, as of January 1, 1967*.

Category	Billions of Short tons
1. Resources determined from mapping and exploration, 0-3000 ft overburden	1560
2. Probable additional resource in unmapped and unexplored areas:	
A. 0-3000 ft overburden	1313
B. 3000-6000 ft overburden	337
Estimated Total Remaining Coal Resources	3210

*Figures are for resources in the ground, about half of which may be considered recoverable.
Source: Geological Survey Bulletin 1275.

1.1.2. Coal Classification According to Physical Characteristics

Coal is classified by <u>rank</u> according to the percentage of fixed carbon and heat content, calculated on a mineral-matter-free basis. As shown in Fig. I-1, the percentage of fixed carbon and the heat content, with the exception of anthracite, increase from the lowest to the highest rank of coal as the percentage of volatile matter and moisture decrease.

The progressive devolatilization and consequent increase in rank of coal are produced primarily by heat and time, and secondarily by structural deformation. Structural deformation may accelerate the process of coal formation, as evidenced by the regional distribution of coal in the United States which shows anthracite in the complexly folded and faulted Pennsylvania field, low-volatile bituminous coal on the moderately deformed Appalachian coal basin, and bituminous coal in the tightly folded synclines of tertiary rocks in Washington State.

Contrary to rank, which expresses the various stages in coal formation, <u>grade</u> refers to the content of ash, sulphur and other deleterious constituents. Ash content ranges from 2 percent to 30 percent, and averages about 10 percent. The sulphur content commonly ranges from 0.5 percent to 8 percent, averaging about 20 percent.

With regard to bed thickness, coal resources are classified as thin, intermediate and thick. The thin deposits are generally unsuitable for mining, except for small scale local use. The intermediate category can be mined with certain equipment limitations, while the thick beds can be mined by all type of mechanical cutting and loading

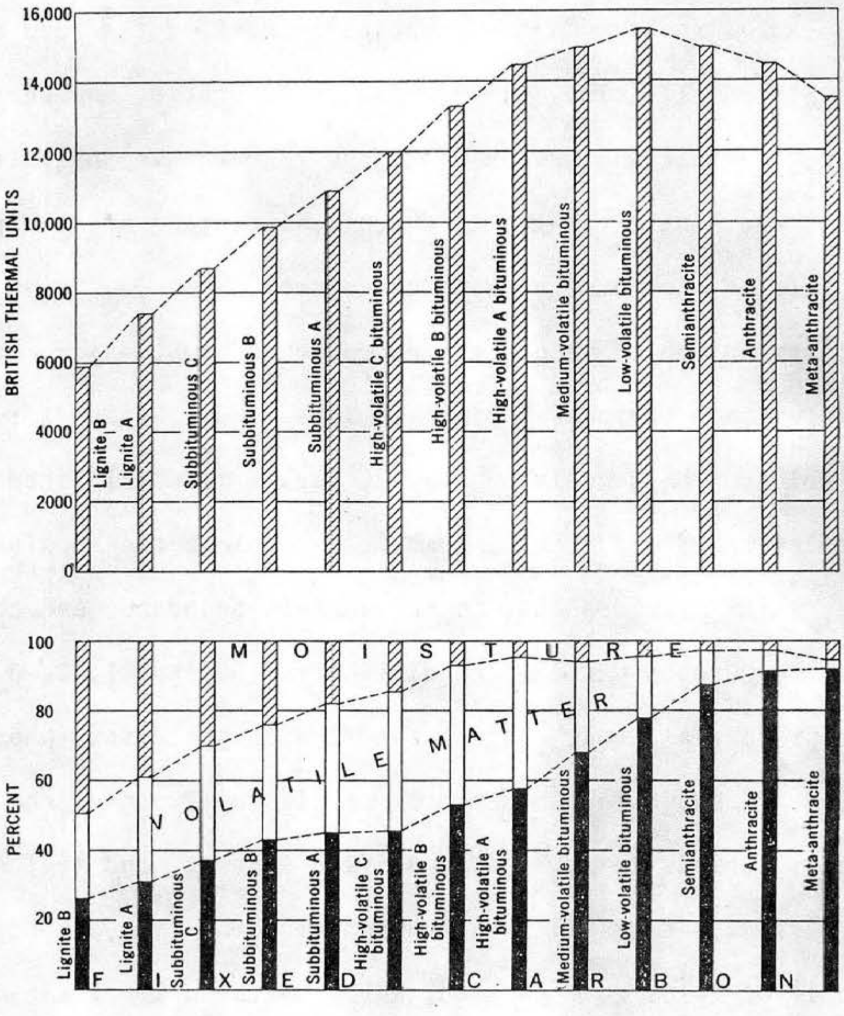

FIG. 1.1. Comparison on moist, ash-free basis of heat values and proximate analyses of coal of different ranks, [1].

machinery. Thick beds for the bituminous type are at least 42 ft thick, and for the subbituminous type at least 10 ft thick.

1.1.3. Regional Distribution of Coal Resources

Coal-bearing rocks underlie about 13 percent of the land area of the United States [1].* They are present in 37 states, including Mississippi, New York and Nevada where the resource is insignificant, and Illinois and West Virginia, in which coal-bearing areas represent more than half of the total area of the state.

The distribution of resources according to eight major coal basins or comparable large regions is given in Table I-2. Region 1 represents coal available to the densely populated, highly industrialized northeastern states. Regions 1 and 2 combined represent the Appalachian coal basin, which provides coal to the eastern seaboard, and coal that is exported to Europe, Canada, and elsewhere. Regions 1, 2, 3 and 4 combined represent all coal east of the Mississippi River, whereas regions 5, 6, 7, and 8 combined represent all coal west of the Mississippi. Regions 1, 2, 3, 4, and 5 lie east of, and regions 6, 7, and 8 lie west of, an imaginary northeast-trending line extending from the panhandle of Texas to Minnesota, which marks an important division of regions and resources according to age and rank of coal. Regions 6 and 7 combined represent the Rocky Mountain and northern Great Plains provinces. Region 8 represents the west coast and Alaska.

With regards to rank, United States coal is distributed quite unequally among five categories. Bituminous coal represents 44.5 percent of the total resource, subbituminous coal represents 26.5

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*Numbers in brackets [ ] refer to the list of references at the end of each chapter.

Table 1.2. Distribution by basin or region, and by thickness of beds, of remaining coal resources of the United States as determined by mapping and exploration, January 1, 1967

(In billions of short tons. Figures are for resources in the ground, about half of which may be considered recoverable. Neg., negligible)

Basin or region	Overburden 0-3,000 ft thick: Resources in thick beds[1] generally less than 1,000 ft below the surface — Tons	Resources in thick beds[1] generally less than 1,000 ft below the surface — Percent of total	Resources in thinner beds less than 1,000 ft below the surface, and in all beds 1,000-3000 ft below the surface.	Total remaining resources (from Table 1)
1. Northern Appalachian basin (Pa., Ohio, W. Va., and Md.)	58	27	157	215
2. Southern Appalachian basin (eastern Ky., Va., Tenn., N.C., Ga., and Ala.)	12	21	44	56
3. Michigan basin.	Neg.	Neg.	Neg.	Neg.
4. Illinois basin (Ill., Ind., and western Ky.)	107	50	104	211
5. Western Interior basin (Iowa, Kans., Mo. Okla., Ark., and Tex.).	11	16	56	67
6. Northern Rocky Mountains (N. Dak., S. Dak., Mont., Wyo., and Idaho). . . .	152	22	544	696
7. Southern Rocky Mountains (Colo., Utah, Ariz., and N. Mex.)	36	20	142	178
8. West coast (Alaska, Wash., Oreg., and Calif.)	24	18	113	137
Total.	400	25	1,160	1,560

[1] Includes bituminous coal and anthracite in beds 42 in. or more thick, and subbituminous coal and lignite in beds 10 ft or more thick.

Source: Geological Survey Bulletin 1275

percent, lignite 27.5 percent, and anthracite 1.5 percent.

In the United States (excluding Alaska) about 83 percent of the bituminous coal and anthracite lies east of an imaginary northeast-trending line extending from the panhandle of Texas to Minnesota, and about 99 percent of the subbituminous coal lies west of that line. The younger, western coal attains high rank only where it has been deformed and altered by the forces that accompanied mountain building.

The subbituminous coal and lignite in the West tend to crumble during transportation and to ignite by spontaneous combustion if stored for too long a period without special precautions. On the other hand, the low-rank coals are well-suited for the production of electric power, synthetic gas and liquid fuels, and in many parts of the West they can be mined effectively by stripping methods. With these advantages, the low-rank coals in the western United States are certain to receive increased attention in the future.

Low-volatile bituminous coal is the most valuable rank because it is very strongly coking, and can be used in blends to upgrade larger resources of high-volatile bituminous coal, which is less strongly coking. Another significant advantage is that the low-volatile ranks contribute much less to air pollution than lower rank coal. It is found in the states of Pennsylvania, West Virginia, Maryland, Virginia, Alabama, Oklahoma, Arkansas and Colorado, and the resource totals about 20 billion tons. This figure is about 1.2 percent of the total resource of the United States.

1.1.4. Stripping-Coal Resources

Table I-3 presents the estimated original resources of stripping-coal in the United States [2]. The estimated total of 139,969 million tons is for original resources in the ground. Subtracting the cumulative past strip production of bituminous coal and anthracite, and assuming an 80 percent recoverability of the remaining resource, the estimated actual resource stands at 108 billion tons. Other estimates [3] for the remaining total resource present a figure of 118 billion tons, out of which only 45 billion are considered strippable reserves.

1.1.5. The Strip Mining Industry in the United States

Some of the earliest coal mining practices in North America was what would now be called strip mining. Certainly the settlers could only employ manual methods for the removal of outcropping coal, and when the depths of overburden increased, animal labor and rudimentary mechanical equipment were used. Increasing demand and limitations in the availability of capital made possible a shift to underground mining. Thus the importance of strip mining declined, and production became insignificant on a national level by the 1830's.

The invention of the steam shovel by William S. Otis in 1839 paved the way for the development of "modern" strip mining. In many respects, the history of strip mining parallels that of the powerful machinery needed for the increase in productivity and cost reduction. The first recorded [4] use of the steam shovel in strip mining was in 1877 near Pittsburg, Kansas. By 1881, the steam shovel was being used in strip mining in Hazleton, Pennsylvania, and its use was very common by the turn of the century.

Table 1.3. Estimated original resources of stripping coal in the United States in beds generally less than 100 feet below the surface

(Figures are for resources in the ground, of which 80 percent may be considered recoverable)

State	Millions of short tons	State	Millions of short tons
Alabama	800	North Dakota	50,000
Alaska	2,000	Ohio	5,000
Arizona	100	Oklahoma	500
Arkansas	263	Pennsylvania	8,000
Colorado	1,200	South Dakota	400
Illinois[1]	23,000	Tennessee	200
Indiana	3,524	Texas	3,282
Iowa	600	Utah	300
Kansas	600	Virginia	1,000
Kentucky	6,000	Washington	100
Maryland	100	West Virginia	6,000
Missouri	1,000	Wyoming	10,000
Montana	15,000		
New Mexico	1,000	Total	139,969

[1]Overburden, 0-150 feet thick.

Source: Geological Survey Bulletin 1252-C

The following decades were to see many improvements in strip mining equipment. A revolving type steam shovel mounted on short sections of rail improved efficiency, as did the introduction of the dragline. The electrification of stripping machinery, starting about 1912, and the walking dragline, introduced by the late 1930's, represented major advances. Yet in spite of these improvements, equipment remained primitive by present standards. The first steam shovels had a capacity of only one cubic yard. Capacity grew slowly, and by the start of World War II very few machines had a capacity of as large as 35 cubic yards.

The relatively primitive nature of the early equipment does much to explain the fact that strip mining attracted little public attention throughout most of its history. While the early steam shovel could not produce a great amount of coal, neither could it do great harm. Thus there were very few complaints about strip mining before World War II. Most of these centered around the damage done to good farmland and the subsequent reduction in the local tax base. West Virginia was the only state to impose any significant regulations on the strip mining industry before the war. The post war period saw a vast increase in the power and versatility of equipment available to the strip mining industry. The most spectacular example is the increase in capacity of the shovels. In 1941, the largest shovel had a capacity of 17 cubic yards. By 1957, shovel capacity had reduced 70 cubic yards. In succeeding years, larger shovels of up to 220 cubic yards capacity were introduced.

The development of equipment of larger size and increased efficiency kept pace with the larger shovel capacity. Walking draglines have been constructed in capacities up to 220 cubic yards [5] and the current trend seems to favor these machines over the shovels of the 75-200 cubic yards capacity size range. New types of booms can be found in some of the latest models of walking draglines. An aluminum boom that sharply reduces weight while lowering the inertia forces that must be overcome in swing, has recently been introduced.

Wheel excavators of the type used for many years in the brown coal areas of Western Germany have been used on a limited scale in the United States since 1944 [6]. These wheels are highly efficient for the removal of soft and unconsolidated overburden, and they are technologically appealing because the operation is continuous and the brokendown overburden can be delivered by conveyor belt to any point desired. A wheel excavator erected in southern Illinois in 1972 has a 480 ft reach and is the biggest machine of this type built to this date in the Western Hemisphere [7].

Strip miners now had not only the capacity but also the incentive to increase production. Given the availability of adequate equipment, strip mining has become much more profitable than deep mining in many areas. This is so for many reasons: productivity per man is higher, capital requirements are lower and the entire operation is more flexible. Thus it is hardly surprising that strip mining increased rapidly. In 1940, 9.2 percent of the bituminous coal and lignite produced in the United States was mined by stripping; by 1950 the figure was 23.9 percent and by 1974 it had reached an all-time high of 49.9 percent.

The increase in size and efficiency of strip-mining machinery has permitted a steady increase in the average maximum thickness of overburden that can be removed and a parallel increase in the ratio of average overburden thickness to average coal thickness. This trend is shown in Table I-4.

The averages presented in Table I-4 include several noteworthy extremes. In Alaska, for example, the average thickness of overburden removed in 1965 was nearly 67 feet, and the average thickness of coal recovered was nearly 43 feet; these figures yield a very favorable statewide ratio of 1.4:1. In marked contrast, the average thickness of overburden removed in Oklahoma in 1965 was 43 feet, and the average thickness of coal recovered was 1.5 feet; these figures yield a statewide ratio of 29:1 [8]. In at least one operation in Kansas, 45 feet of overburden was removed to obtain 1.5 feet of high-quality coal; these figures yield a ratio of 30:1. In Illinois ratios larger than 30:1 have been handled and are being planned in parts of large-scale stripping projects where the coal is 28-36 inches thick.

These examples suggest that the 30:1 ratio is technically feasible as a maximum for present and near-future strip mining. However, in the present highly competitive energy market, the success of each strip-mining operation depends on many economic factors other than thickness of the overburden. These factors include thickness and quality of the coal, density and hardness of the overburden, capacity of machinery, size of property, selling price of coal from competing sources, distance

Table 1.4. Average thickness (in ft) of overburden removed and of bituminous coal and lignite recovered by strip mining in the United States for selected years

	1946	1950	1955	1960	1965
Average thickness of overburden removed.	32	39	42	46	50
Maximum thickness of overburden removed.	-----	-----	70+	100	125
Average thickness of coal recovered. . .	5.2	5.1	4.9	5.1	5.2
Ratio of average overburden thickness to average coal thickness	6:1	8:1	8:5:1	9:1	10:1

Source: Geological Survey Bulletin 1252-C to transportation facilities and markets, and availability of electric power, labor and supporting facilities. Because of the continued availability of coal with more favorable overburden ratios, the average nationwide ratio will continue to be less than 30:1 for many years; as may readily be seen by an examination of the average ratios for the years shown in Table I-4.

The thickest bed mined by stripping is at Wyodak, Wyoming, where the coal is 90 feet thick; the overburden is generally less. The deepest strip pits in the United States are in the Pennsylvania anthracite fields where two major types of strip mining, termed "coutour stripping" and "area stripping," are in progress.

In contour stripping, operations proceed linearly and downdip along a steeply dipping outcrop. These outcrops were first mined many years ago by underground methods, which recovered about one-third of the coal. Later, during the 1920's and 1930's, they were stripped out along a very narrow shallow belt with small shovels. In the current operations the partly mined coal belt just below the older stripped-out zone is being recovered with large draglines and shovels. These pits are as much as 200 feet deep.

In area stripping, the entire canoe-shaped end of a syncline is mined out and backfilled on a massive scale. In one such operation where the 20-foot-thick Mammoth bed lies in the syncline, the block of ground being strip mined is 800 feet wide and 290 feet deep at the deepest place on the synclinal axis.

Strip mining greatly increases the amount of ultimately recoverable coal in the United States, for the method yields an average recovery of about 80 percent as compared to 50 percent for underground mining. Strip mining also adds to total recoverable coal by making possible the mining of coal under shallow overburden, in thin beds, in multiple beds, in badly faulted areas, or in small isolated pockets where underground mining would not be practicable.

The rapid expansion of strip mining has confronted the industry with a wave of opposing public opinion. The principal reason was the enormous increase in the amount of land being stripped. However, there were other reasons, the two most important of which appear to have been: 1) the intensive stripping of Appalachia. Stripping mountainous areas produces spectacular, highly visible scars and often causes great property damage. Unfortunately for the strippers, their move into Appalachia coincided with the latest rediscovery of the region by the American public. Thus the activities of the strippers and the protests of their opponents were given wide coverage in the communications media; 2) the recent concern with the damage to the environment. Strip mining was an all-too-obvious target for the attacks of those concerned with the quality of the environment.

The issue appears to be between the abolitionists and the reclamationists. The abolitionists, citing the worst examples in Appalachia, maintain that adequate reclamation is impossible. The reclamationists, citing the best examples in Indiana, maintain that the stripping and reclamation cycle actually increases the value of the land. Only a few seem to be willing to recognize that there are substantial differences between stripping on flat land and on a steep slope.

The increasing energy requirements of the country and the shortage of alternative fuels make nationwide abolition of strip mining an unlikely prospect in the near future. Thus disputes over practices and policies will continue with some variations in both theme and tone. For example, much of the strip mining may shift from Appalachia to the Western Plains. However, the basic social, economic and political concerns will remain.

1.2.0 Environmental Impact of Strip Mining

Environment is defined as the surrounding conditions or forces that interact with living and non-living things to shape and modify them. Within this broad context, physical, biological and social factors need to be considered. Therefore, the term environment encompasses almost every aspect of life and nature.

Throughout geologic time the earth's physical environment has been subjected to a continuing cycle of orogeny, erosion, transportation and deposition. These geomorphic changes need not be regarded as either recent or undesirable. On the other hand, short-span changes brought upon by the action of man, may be of such a magnitude as to considerably jeopardize the natural balance among the various constituents of the environment.

Strip mining is widely regarded as an example of the interference of man in the natural process of evolution of the landscape. Once the vegetative cover has been removed, the broken soil and rock left in massive piles can be easily subject to erosion. The result is a drastic reshaping of the land and an alteration of surface and subsurface drainage patterns.

The environmental impact of strip mining can be assessed by determining its effect on the quality of air, land and water, and through these, animal and plant life. Strip mining per se is not a major contributor to air pollution, although dust and noise from mining operations can be annoying if located near densely populated areas. The major impact is manifested in the detrimental effect to the land and water resources. These will be considered separately in the following sections.

1.2.1. Disturbance of the Land

The major effect of strip mining on the land is the impairment in the ability to sustain vegetation. Two factors that are essential to the establishment of vegetation on stripped mined lands are the physical and chemical characteristics of the spoil. A study of the spoil material obtained in a random sampling survey [9], found that in only 25 percent of the sites observed the spoil was suitable for agriculture. Most of the remaining sites showed evidence of erosion in the form of gullies less than one-foot deep; but, at 10 percent of the sites gullies that exceeded this depth were found. Sediment deposits were found in 56 percent of the ponds and 52 percent of the streams on or adjacent to the sample sites.

Spoil bank materials which have a pH of 4.0 or less are lethal to most plants. A pH of 7.0 is neutral; values higher than 7.0 indicate alkalinity. Free acid may be leached enough in 3 to 5 years to permit planting, but the leaching process will not improve soil conditions if erosion is allowed to expose more sulfuritic minerals in the spoil. Although some plants achieve successful growth in spoil with a pH range under 5.0, most plants require a less acid environment for successful growth. Of the measurements taken on spoil banks, 1 percent showed a pH of less than 3.0 and 47 percent, a range between pH 3.0 and 5.0.

1.2.2 Water Pollution

Taken on a nationwide basis, strip mining is not a major source of water pollution. This is due to the fact that very few areas have been subject to strip mining disturbance, the percentage of the total land area of the United States amounting to less than 0.15 percent [9]. On a regional basis, though, surface mining accounts for most of the damage to streams in the form of chemical drainage and sediment clogging.

Chemical pollution of water by surface mining disturbances takes different forms. The polluted water may be too acid, too alkaline or contain excessive concentrations of dissolved substances such as iron, manganese and copper. Sulphur-bearing minerals are commonly associated with coal, and in some regions are a major cause of water pollution. When exposed to air and water, they oxidize to form sulfuric acid, which then contaminates both the surface and subsurface waters.

Acid drainage is one of several adverse effects of chemical water pollution caused by surface mining. Even in very small concentrations, salts of metals such as zinc, lead, copper and aluminum are toxic to fish and fauna. A study conducted by the Bureau of Sport Fisheries and Wildlife [10] concluded that the potential fish and wildlife waters deleteriously affected by acid mine pollution totaled 5890 miles of streams and 14,976 acres of impoundments.

Physical pollution is most serious in areas of concurrent high intensity storms, and steep topography, as evidenced by the measured sediment yields in the mountainous regions of Appalachia. Collier et. al. [11] report on a study of the influence of strip mining in the hydrologic environment of Beaver Creek, Kentucky.

Their report states that natural vegetation has not been sufficient to reduce the rate of weathering and erosion of the spoil material, and the spoil banks have continued to be the predominant source of sediment to the stream. Both sheet erosion and gully erosion have been active on the spoil banks. Large gullies eroded into the steep outer edges of the spoil banks were the source of much of the material removed. From 1958 to 1966, the top of the southwest spoil bank was lowered 0.3 foot by sheet erosion. Part of the spoil bank, whose steep outer slope was rilled and partly terraced, was eroded at an average annual rate of 14.8 cubic yards per acre, while in an area drained by a large gully, the annual rate of erosion was 159 cubic yards per acre. Gully erosion in the spoil banks has increased with time, whereas sheet erosion has decreased with time.

Much of the sediment that was eroded from the spoil banks by surface runoff was transported into the stream and greatly increased the sediment concentrations and sediment discharges. Sediment concentrations during the study period commonly exceeded 30,000 ppm during storms, whereas the maximum concentration was only 553 ppm in 2½ years of record at a neighboring stream not affected by the strip mining. The annual sediment yield from areas not affected by mining averaged about 25 tons per square mile compared with an average of more than 1,900 tons per square mile for those affected, during the 4 years following cessation of mining. The average annual sediment yield from the spoil banks was about 27,000 tons per square mile during this period, more than a thousand times greater than the yield from undisturbed areas. Most of the sediment is transported during intense storms in the warm months.

One of the major causes of sedimentation problems is the failure to provide for the control of surface runoff during and immediately following a storm. As a result of this neglect, some 7,000 miles of streams [9] have had their normal flood-discharge carrying capacity reduced by sediment clogging. Efficient runoff control practices that will considerably minimize the associated environmental hazard are yet to be implemented on a nationwide scale.

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Chapter II

SEDIMENT SOURCES AND YIELDS

2.1.0. Introduction

Sediment yield is the outcome of a natural process encompassing the erosion of soil at the source and transportation of the soil particles by the force of climatic agents, or more commonly, water. The pervading nature of the erosion process accounts for its wide distribution both in time and space, and its importance can hardly be overemphasized. Moreover, because the process can be accelerated or decelerated by a multitude of factors, including the action of man, the understanding of the physical phenomena has received widespread attention.

In the United States, scientists and engineers have been concerned about sediment yield for about 100 years [1]. Only recently, however, the water quality implications of sediment have been recognized. Seeing sediment in this new light demands an improvement in the technology for estimating sediment yields and selecting effective measures for sediment management. The recent trend seems to be to evaluate sediment yield and properties in relation to its sources, coupled with an increased concentration on the regulation of the supply.

Strip mining, particularly in coal fields of the eastern United States, is an important source of sediment. Spoil banks resulting from contour stripping are often steep-sided and consist of a loose, heterogeneous mixture of soil and unweathered rock materials that are devoid of vegetation. In forested areas of Appalachia where the natural sediment yields are low, erosion from extensive areas of unreclaimed spoil banks have caused serious sedimentation problems in the streams [2].

The remainder of this chapter will review various methods for the prediction of the amount of sediment generated in a particular watershed. Techniques for the evaluation of erosion rates and sediment yields will be considered. Although these techniques have been largely developed for general applicability, their use for small watersheds (strip-mined watersheds) will be emphasized.

Definitions

The following definitions are presented in an effort to clarify the material that follows.

Sheet erosion: removal of a thin layer of the land surface.

Rill erosion: removal of soil by small concentrations of flowing water, with the formation of small channels that can be smoothed by normal cultivation methods.

Gully erosion: removal of soil by large concentrations of flowing water, with the formation of large channels that cannot be smoothed completely by normal cultivation methods.

Rate of erosion: the rate at which soil is removed from the source, expressed in volume or weight per unit area per unit time.

Soil loss: the quantity of soil removed from a test area in a given time.

Sediment yield: the total sediment outflow from a watershed or drainage basin, measured at a given location and in a specified period of time.

Sediment delivery ratio: a ratio of the amount of sediment yield to the amount of sediment originating at the source.

2.2.0. Erosion Rates from Sediment Sources

The need for quantitative information on soil erosion rates led to the establishment of small test plots, instrumented to determine soil loss under a wide variety of environmental conditions. Data from plot studies of sheet erosion made it possible to develop general relationships to predict the rate of soil loss. Musgrave [3] consolidated previous work and developed the following empirical equation:

$$E = FR \left(\frac{S}{10}\right)^{1.35} \left(\frac{L}{72.6}\right)^{0.35} \left(\frac{P}{1.25}\right)^{1.75} \tag{2.1}$$

where E = the probable soil loss, measured either in tons per acre per year, or in inches per year; F = an erodibility factor for the specific soil considered, measured in the same units as E; R = a dimensionless cover factor; S = the land slope, expressed as a percentage; L = slope length, in ft; and P = the 30-min 2-yr frequency rainfall, in inches.

This predictive equation led the path for the development of a more sophisticated model, widely known as the Universal Soil Loss Equation.

The Universal Soil Loss Equation, as presented by Wischmeier and Smith [4] is:

$$A = R\ K\ L\ S\ C\ P \tag{2.2}$$

where A is the computed annual soil loss per unit area,

R, the rainfall factor, is the number of erosion-index units in a normal year's rain. The erosion index is a measure of the erosion force of specific rainfall.

K, the soil erodibility factor, is the erosion rate per unit of erosion index for a specific soil in cultivated continuous fallow, on a 9 percent slope 72.6 ft long.

L, the slope-length factor, is the ratio of soil loss from the field slope length to that from a 72.6 ft length on the same soil type and gradient.

S, the slope-gradient factor, is the ratio of soil loss from the field gradient to that from a 9 percent slope.

C, the cropping-management factor, is the ratio of soil loss from a field with a specified cropping and management, to that from the fallow condition on which the factor K is evaluated.

P, the erosion control practice factor, is the ratio of soil loss with contouring, strip cropping, or terracing to that with straight-row farming, up-and-down slope.

The soil loss equation provides a methodical means of bringing the effects of expected rainfall pattern, soil properties, and land use into computation of that part of the sediment production that is attributable to sheet and rill erosion. The watershed under study may be divided into a number of tracts having relatively homogeneous land use and treatment. The soil loss equation is then used to estimate the average annual rate of soil erosion from each tract. Other sources of sediment production that must be considered in making estimates of total sediment loads include gully and channel erosion. Gully erosion will be treated sepately in Section 2.4.0.

The Rainfall Factor R: When factors other than rainfall are held constant, storm soil losses from cultivated fields are directly proportional to the product value of the rainstorm characteristics: total kinetic energy of the storm times its maximum 30-minute intensity (EI). This product variate is an interaction term that reflects the combined potential of raindrop impact and turbulence of runoff to transport dislodged soil particles from the field.

The sum of the computed storm EI values for a year is a numerical measure of the erosivity of all rainfall for that year. The rainfall factor R is the average annual value of the EI products. Maps showing the R values have been developed for the United States east of the Rocky Mountains, and values for the United States east of 105^{o}W are shown in Fig 2.1. Corresponding maps for the mountainous western United States have not been developed due to the difficulty in assessing the rainfall pattern in that region.

R values for the United States east of the Rocky Mountains range from 50 to 600. If soil and topography were exactly the same everywhere, average annual soil losses would be in direct proportion to the R values shown. This potential difference is, however, partially upset by differences in soil, topography and vegetative cover. On humid areas, good vegetal cover protects the soil from erosion, while on semiarid regions, rainfall is seldom adequate for the establishment of good cover. Hence, serious soil-erosion hazards exist in semiarid as well as in humid regions.

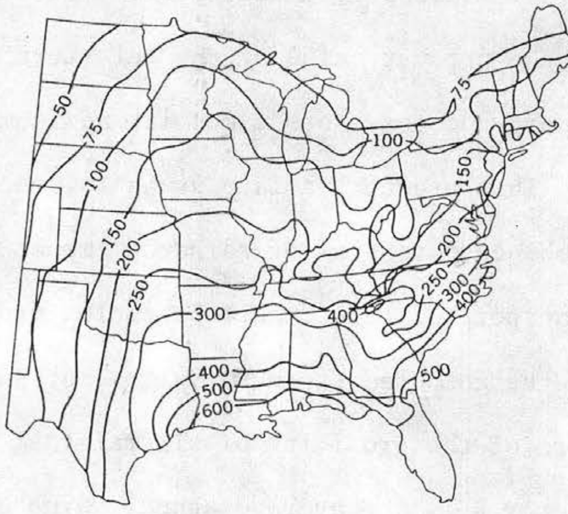

FIG. 2.1. Average Annual Values of Rainfall Erosivity factor R for the area of the United States east of 105° W, [4].

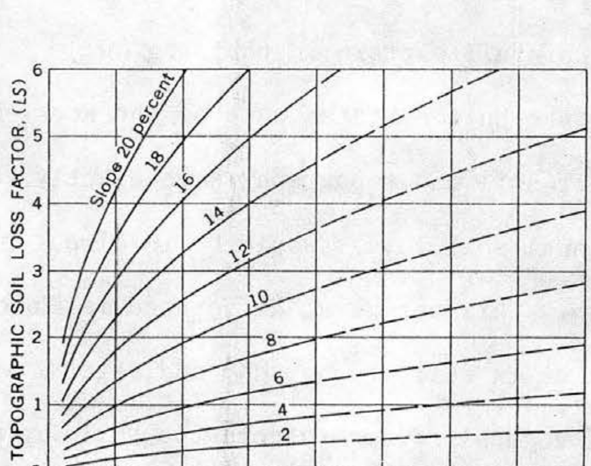

FIG. 2.2. Slope-effect chart (topographic factor, LS), [4].

The Soil Erodibility Factor: The soil erodibility factor, K, is a quantitative value, determined experimentally. For a particular soil, it is the rate of erosion per unit of rainfall factor from unit plots. A unit plot is a 72.6 ft long, with a uniform lengthwise slope of 9 percent, in continous fallow, tilled up and down the slope.

Values of K determined for 23 major soils on which erosion plot studies were conducted since 1930 are listed in Table 2.1. Seven of these values are from continuous fallow. The others are from row crops averaging 20 plot-years of record per location and requiring a minimum of adjustment for management effects.

Soil erodibility values for other soils have been estimated by comparing their characteristics against the established values for the 23 soils listed in Table 2.1.

Factors for Slope Length (L) and Gradient (S): The rate of soil erosion by water is a direct function of slope length and gradient. Both effects can be evaluated separately. However, in field applications it is convenient to consider the two as a single topographic factor, LS.

The factor LS is the expected ratio of soil loss per unit area on a field slope to the corresponding soil loss from the basic 9 percent, 72.6 ft long plot. This ratio, for specific combinations of slope length and gradient, can be obtained from Fig 2.2. In using this figure as a guide on an area where several slopes are present, such as would be likely in a strip mining operation, the slope characteristics of the most erosive segment should be used in Fig 2.2.

TABLE 2.1

VALUES OF THE SOIL ERODIBILITY FACTOR K [4].

SOIL	SOURCE OF DATA	COMPUTED K
Dunkirk silt loam	Geneva, N.Y.	[1]0.69
Keene silt loam	Zanesville, Ohio	.48
Shelby loam	Bethany, Mo.	.41
Lodi loam	Blacksburg, Va.	.39
Fayette silt loam	LaCrosse, Wis.	[1].38
Cecil sandy clay loam	Watkinsville, Ga.	.36
Marshall silt loam	Clarinda, Iowa	.33
Ida silt loam	Castana, Iowa	.33
Mansic clay loam	Hays, Kans.	.32
Hagerstown silty clay loam	State College, Pa.	[1].31
Austin clay	Temple, Tex.	.29
Mexico silt loam	McCredie, Mo.	.28
Honeoye silt loam	Marcellus, N.Y.	[1].28
Cecil sandy loam	Clemson, S.C.	[1].28
Ontario loam	Geneva, N.Y.	[1].27
Cecil clay loam	Watkinsville, Ga.	.26
Boswell fine sandy loam	Tyler, Tex.	.25
Cecil sandy loam	Watkinsville, Ga.	.23
Zaneis fine sandy loam	Guthrie, Okla.	.22
Tifton loamy sand	Tifton, Ga.	.10
Freehold loamy sand	Marlboro, N.J.	.08
Bath flaggy silt loam with surface stones >2 inches removed	Arnot, N.Y.	[1].05
Albia gravelly loam	Beemerville, N.J.	.03

[1]Evaluated from continuous fallow. All others were computed from row-crop data.

<u>The Cropping-Management Factor C</u>: The factor C in the soil loss equation is the ratio of soil loss from land cropped under specified conditions to the corresponding loss from tilled, continous fallow. This factor measures the combined effect of all cover and management practices.

The loss that would occur on a particular field if it were continuously in fallow condition is computed by the four factor product, RKLS. In a cropped field, actual loss is usually much less than this amount. Just how much less will depend on the crop and management practices. The factor C adjusts the soil loss estimate to suit these conditions.

In a strip mined field, the factor C should approximate unity. This factor decreases considerably, though, if some type of vegetative cover is considered immediately after mining. The following C factors will represent average conditions in most cases:

Well established grass	C = 0.01
Weeds and wild grass	C = 0.10
Disturbed area (in fallow)	C = 1.00

For a more detailed treatment of the factor C, the reader is referred to reference [4].

<u>The Erosion Control Practice Factor</u>: The factor P in the soil loss equation is the ratio of the soil loss in a field with a certain erosion control practice, to that in an up-and-down hill practice. Its applicability in estimating erosion soil loss in strip-mined lands has not been adequately quantified. However, for lack of a

better approximation, the following table has been adapted from reference [4].

Table 2.2. Erosion Control Practice Factor P.

Land Slope (percent)	P
1.0 - 12.0	0.60
12.1 - 18.0	0.80
18.1 - 24.0	0.90
>24	1.00

Example: Assume a strip mining site in Eastern Colorado. The disturbed area is 10 acres, the average slope of the spoil banks is 20%, and the slope length is 200 ft. The soil is a silty loam with a K value of 0.35, determined by a comparison with similar soils in the region. The disturbance will last six months, after which vegetative cover will be established. An estimate of the soil loss due to the mining is required.

The value of R can be estimated from Fig. 2.1. The geographical location known, it will be assumed that R = 75. The value of LS can be obtained from Fig. 2.2, for L = 200 ft and S = 20%, LS = 6. An estimate of the soil loss due to the disturbance caused by the mining operation will require that C be equal to 1. Finally, P = 0.90 from Table 2.2. Using all the previous values in Eq 2.2.:

$$A = R\ K\ L\ S\ C\ P$$
$$= 141.6 \text{ tons/acre/year}$$

The total amount of soil loss for the 10-acre site during the 6 month period will be:

$$A_T = 708 \text{ tons}$$

2.3.0 Erosion in Gullies

Gullies, or upland channels, are common to most regions, and their development is usually associated with severe climatic events, improper land use, or changes in stream base level. Most of the significant gully activity, in terms of quantities of sediment produced and delivered to downstream locations, is found in regions of moderate to steep topography having thick soil mantles. The total sediment outflow from eroding gullies, though large, is usually less than that produced by sheet erosion [5]. However, the economic losses from dissection of upland fields, damage to roads and drainage structures, and deposition of relatively infertile overwash on flood plains are disproportionately large.

A field study of gully activity in several locations throughout the United States has resulted in the tentative relationship [6].

$$R = 0.15\ A^{0.49}\ S^{0.14}\ P^{0.74}\ E^{1.00} \tag{2.3}$$

in which R = average annual gully head advance, in ft; A = drainage area, in acres; S = slope of approach channel, as a percentage; P = annual summation of rainfall, in inches; for storms equal to or greater than 0.5 in/24 hr; and E = clay content of eroding soil profile, as a percentage by weight.

Seginer [7] has found that gully erosion strongly correlates with the size of drainage basin. He suggests that gully erosion problems of a particular site or drainage basin can be evaluated from an equation of the form:

$$R = CA^{b} \tag{2.4}$$

in which R = average annual gully head advance; A = area of drainage basin; and C and b = constants. Since C is postulated constant, the relative advance depends on the value of b. The variation of b between regions and watersheds of the same region will reveal the effect of soils, topography, land use and management. This procedure will allow the planner to place the proper emphasis on a particular problem, such as land use and management in the case of strip mining.

2.4.0. Sediment Yield

Not all of the soil loss is effectively sluiced through the river systems and delivered to the sea. The rate at which sediment is discharged to the oceans is usually less than one-fourth of the rate at which it is eroded from the land surface [8]. The bulk of the sediment is deposited at intermediate locations wherever the energy of the runoff water is insufficient to sustain transport. This effect is quantified by defining a sediment delivery ratio D expressed as a percentage as:

$$D = 100 \frac{Y}{T} \tag{2.5}$$

where Y = the sediment yield at the measuring point, in tons per acre per year; and T = the total material eroded from the watershed and drainage system upstream from the measuring points, in tons per acre per year.

The prediction of sediment yield can be made by using one of the following methods:

1. The sediment delivery ratio method.
2. The sediment yield from streamflow sampling.
3. The reservoir survey method.
4. The sediment transport relationship methods.
5. The sediment transport models.
6. Sediment yield mathematical models.
7. Special methods.

2.4.1. The Sediment Delivery Ratio Method

This method requires the knowledge of the value of D in Eq. (2.5.), developed from sediment yields obtained by reservoir surveys or measurements at suspended load stations, in comparison with the soil loss in the watershed. The soil loss is computed by erosion prediction equations such as the Universal Soil Loss Equation. Gully and channel erosion are accounted for where applicable.

Sediment delivery ratios have been developed for much of the eastern half of the United States, but incomplete data has precluded use of the method in the West.

2.4.2. The Streamflow Sampling Method

This method requires concurrent field measurement of stream flow and sediment, measured from individual runoff events. The method is often used for establishing the amount of sediment expected to reach large reservoirs or other points on principal tributaries and main rivers. Present streamflow sampling methods are costly, and the measured suspended sediment discharge should often be adjusted upwards by some estimation procedure to account for the unmeasured bed material discharge in close proximity to the stream bed (see Section 3.1.3.).

2.4.3. The Reservoir Survey Method

This method involves the measurement by field survey of the volume of sediment accumulated in a pond or reservoir. The measured volumes are converted into weights, adjusted for reservoir trap efficiency, and expressed as rates of accumulation according to the age of the reservoir or the time interval between surveys. This source of sediment yield information is especially advantageous to persons engaged in pond and reservoir design, because the location of deposited sediments and the sediment quantities involved are determinant in the design. Additional information on this method can be found in references [9] and [10].

2.4.4. The Sediment Transport Relationship Method

In all but the largest rivers, the runoff entering a stream channel forms the bulk of the sediment in transport. This runoff represents the integrated effect of the characteristics of the drainage basin that relate to sediment production. The sediment entrained in the runoff consists of: a) the finer portion, or washload; and b) the coarser portion, or bed material load. The wash load particles are relatively insensitive to the flow parameters, and its amount is dependent on the available supply. The amount of bed material load is dependent upon a balance between the supply and the flow parameters. Bed material load can be transported in suspension (suspended load) or in contact with the bed (bed load).

A sediment transport relationship can be obtained by correlation from measured data. Measuring techniques are described in detail in Chapter III. Typically, a suspended sediment transport relationship will show a logarithmic plot of sediment discharge vs. water discharge. In general, the curve is concave downward, and has its largest slope at low discharges and its smallest slope at the highest discharge. Segments of a transport relationship of this type can be approximated by an equation of the following form:

$$G_{ss} = L\ Q^{n} \tag{2.6}$$

where

G_{ss} is the suspended sediment discharge,

Q is the water discharge

L is a factor (index of relative erodibility)

n is the slope of the curve in a logarithmic scale

The relative variation of plotted points in the low runoff portion of a sediment transport curve based upon sediment samples can be one hundred-fold (two log cycles), while the variation at the high runoff end is much less.

Many sediment prediction methods are based on the runoff-sediment relationship that exists in any given watershed, coupled with the runoff-frequency data. Runoff frequency information is obtained in a variety of ways, including: a) the extrapolation of annual-duration or partial-duration series of runoff, b) the use of double-mass comparisons of runoff or precipitation records, or both, for the watershed and adjacent areas; and c) an analysis of short-term rainfall-runoff relationships and

TABLE 2.3. Long-Term Sediment Yield by Flow Duration-Sediment Rating Curve Method[a] [8]

Cumulative duration, as a percentage (1)	Duration, as a percentage (2)	Duration midpoint (3)	Flow at midpoint, in cubic feet per second (4)	Co.2X Col.4 (5)	Sediment rate, in tons per day (6)	Co.2X Col.6 (7)
1 - 0	1	0.5	-			
5 - 1	4	3	-			
15 - 5	10	10	0.25	0.025		
25 -15	10	20	0.32	0.032		
35 -25	10	30	0.42	0.042		
45 -35	10	40	0.54	0.054		
55 -45	10	50	0.70	0.070		
65 -55	10	60	0.96	0.096		
75 -65	10	70	1.5	0.150		
81 -75	6	80	4.9	0.294		
87 -81	6	84	6.0	0.360		
91 -87	4	89	13.8	0.552	40	1.60
93 -91	2	92	27.0	0.540	130	2.60
95 -93	2	94	50.0	1.000	340	6.80
96 -95	1	95.5	83.0	0.830	700	7.00
97 -96	1	96.5	125	1.250	1,240	12.40
98 -97	1	97.5	185	1,850	2,020	20.20
98.6 -98	0.6	98.3	260	1.560	3,050	18.30
99.0 -98.6	0.4	98.8	346	1.384	4,290	17.16
99.2 -99.0	0.2	99.1	412	0.824	5,200	10.40
99.4 -99.2	0.2	99.3	474	0.948	6,140	12.28
99.6 -99.4	0.2	99.5	565	1.130	7,450	14.90
99.8 -99.6	0.2	99.7	700	1.400	9,300	18.60
99.9 -99.8	0.1	99.85	890	0.890	12,100	12.10
99.92-99.9	0.02	99.91	1,030	0.206	14,000	2.80
99.94-99.99	0.02	99.93	1,100	0.220	14,900	2.98
99.96-99.94	0.02	99.95	1,200	0.240	16,200	3.24
99.98-99.96	0.02	99.97	1,330	0.266	18,200	3.64
100 -99.98	0.02	99.99	1,620	0.324	22,000	4.40
				Σ=16.537		Σ=171.40

[a]Station 12, Pigeon Roost Creek Watershed, near Holly Spring, Miss.
Note: For Col.5, average annual cumulation=16.537 cfs X 365.25 days -6,040cfs-days. For Col.7, average annual cumulation=171.40 tons/day X365.25 days=62,000 tons.

a knowledge of the long-term rainfall pattern.

The daily runoff-suspended sediment information is used in determining a long term sediment rating curve. The construction of the representative long-term curve, when based on short-term records, requires a familiarity with affecting meteorologic and watershed variables.

When the long-term flow duration and sediment rating curves have been synthesized, the average annual sediment yield can be computed by the method of Table 2.3. The mean runoff rate for each duration increment is obtained from the flow duration curve. It is then used to enter the sediment transport curve and determine the sediment discharge rate for each duration increment.

2.4.5 The Sediment Transport Models

There is a wide variety of sediment transport models, and they have been thoroughly reviewed in the literature [8]. Their use for sediment yield predictions usually relates to aggradation and degradation problems. However, their application is also common in establishing the rate or magnitude of the unsampled sediment discharge in close proximity to the stream bed.

Methods of estimating the suspended sediment discharge in the unsampled layer near the bed and the bed load discharge have been proposed by Colby [11] and Colby and Hembree [12]. (A detailed description of Colby's[11] method for estimating the unmeasured sediment discharge is given in Section 3.1.3.) The latter method, known as the Modified Einstein Method, is based on observed suspended load samples, mean velocity, depth, cross section, and size composition of bed material. Its name derives from the fact that it uses a modified version of the Einstein Bed Load Function [13] in estimating the unmeasured sediment discharge. The sediment discharge based on suspended sediment samples and estimates of the unmeasured discharge are much more reliable than those based on formulas alone.

2.4.6 Mathematical Models for Sediment Yield

In these models an attempt is made to describe mathematically the pertinent hydrological, physicochemical and biological processes to form a rational basis for predicting the amount and composition of sediment yield. Existing sediment yield models are varied in purpose [14]. Some have been designed for small watersheds [15]; others for river basins [16]. Nearly all sediment yield models are second-stage components of runoff-generating models, so their accuracy is largely dependent on the accuracy of the runoff model.

2.4.7. Sediment Yield from Strip Mined Watersheds

The amount of sediment originating in strip mined watersheds can be evaluated by one or more of the methods outlined in the foregoing sections. An additional method, developed strictly from measurements in a strip mined watershed, is reported here. Curtis [17] measured sediment yield in a strip mined watershed in Eastern Kentucky, by measuring the sediment accumulation in debris basins. He concluded that erosion and subsequent sediment yield seem to have a half-life of 6 months. By this he meant that sediment yield during succeeding 6-month periods were measured to be about one-half of the preceding period. He reasoned that according to this observed fact, about half of the total sediment yield is produced during the first 6 months of operation.

For predicting sediment yield for any number of years, the equation is:

$$Y_T = S_1 \frac{2^n-1}{2^{n-1}} \tag{2.7}$$

where Y_T = the total expected sediment yield over a period of T years following initial disturbance.

S_1 = sediment yield for the first 6-month period.

n = number of 6-month periods in T years.

Little correlation has been found between sediment yield and the amount of land disturbed during strip mining activities. Methods or mining and handling the overburden, which will be treated in detail in Chapter V, are major factors controlling sediment yield.

A safety factor should be included in the estimate of sediment yield. Where debris basins are planned, it is recommended [17] that to assure adequate design capacity, 0.20 acre-ft per acre of expected disturbance be retained. Improved reclamation methods in the future will make it possible to relax present design criteria. The highest sediment yields measured during the first 6-month period indicates a need for more attention to activities during and immediately following mining.

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Chapter III

SEDIMENT MEASUREMENT TECHNIQUES

3.1.0 Field Measurement of Fluvial Sediment

Fluvial sediment measurement constitutes a significant aspect of sediment yield evaluation. The accuracy of the measurements, however, is dependent not only upon the equipment and techniques utilized, but also upon a knowledge of basic concepts of fluvial sedimentation. Some of these concepts will be reviewed here for the sake of completeness, and the following sections will cover the equipment and techniques currently in use for fluvial sediment measurements.

Modes of Sediment Transportation

As the sediment reaches the stream, it separates itself into: a) the finer fraction, and b) the coarser fraction. The finer fraction, or wash load, is relatively insensitive to the flow parameters, and its amount is related to the erosive potential of the watershed. The coarser fraction is called "bed material load," and as its name implies, consists of sediment of sizes significantly represented in the channel bed.

The bed material load is transported by the water in two distinct modes: 1) in suspension, and 2) in contact with the bed. The sediment lifted from the bed and transported in suspension by the turbulence of the stream is called "suspended load," and the sediment that is transported by rolling and sliding in contact with the bed is called "bed load."

Very often the term "suspended sediment discharge" is used to describe the summation of the suspended load and the wash load.

The term "measured suspended sediment discharge" is used to describe that fraction of the suspended sediment discharge that can be sampled with available techniques, and in general excludes a certain fraction of the suspended sediment discharge adjacent to the stream bed.

The amount of washload released by the drainage basin is transported in suspension by the stream. The transport of bed material load, though, is dependent on the carrying capacity of the stream, i.e., the hydraulic parameters of the flow. For stream bed equilibrium, the availability of bed material load should be balanced with the carrying capacity. In cases where significant imbalances occur, it results in aggradation or degradation of the channel bed, with the undesirable side effects that usually accompany these phenonema.

Concentration of Suspended Sediment

A concentration of suspended sediment can be determined as the ratio of the weight of dry sediment to the weight of the water-sediment mixture, and expressed in parts per million (ppm). To convert the concentration in ppm to milligrams per liter (mg/l), the applicable factor ranges from 1.0 at concentrations between 0 and 15,900 ppm, to 1.5 for concentrations between 529,000 and 542,000 ppm (Table 3.1).

Vertical Distribution of Suspended Sediment

The suspended sediment concentration generally is at a minimum at the water surface, and a maximum near the stream bed. The coarsest fractions of the suspended sediment, usually sand, exhibit the greatest variation in concentration from the stream bed to the water surface. The finer fractions, mostly silt and clay, have a

Table 3.1. Factor A to convert concentration in ppm to milligram per liter.

$\frac{\text{Weight of Sediment}}{\text{Weight of Sediment and Water}} \times 10^6$ (1)	A (2)	$\frac{\text{Weight of Sediment}}{\text{Weight of Sediment and Water}} \times 10^6$ (3)	A (4)
0- 15,900	1.00	322,000-341,000	1.26
16,000- 46,900	1.02	342,000-361,000	1.28
47,000- 76,900	1.04	362,000-380,000	1.30
77,000-105,000	1.06	381,000-398,000	1.32
106,000-132,000	1.08	399,000-416,000	1.34
133,000-159,000	1.10	417,000-434,000	1.36
160,000-184,000	1.12	435,000-451,000	1.38
185,000-209,000	1.14	452,000-467,000	1.40
210,000-233,000	1.16	468,000-483,000	1.42
234,000-256,000	1.18	484,000-498,000	1.44
257,000-279,000	1.20	499,000-513,000	1.46
280,000-300,000	1.22	514,000-528,000	1.48
301,000-321,000	1.24	529,000-542,000	1.50

[a]Based on density of water of 1.000 g/ml, plus or minus 0.005 in the range of temperature 0°C-29°C, dissolved solids concentration between 0 ppm and 10,000 ppm, and the specific gravity of sediment of 2.65.

nearly uniform distribution over the depth of the stream. For conditions of steady uniform flow, the concentration C, of a given size-fraction of suspended sediment in a natural sand bed stream varies with depth in such a manner that a plot of (d-y)/y against C_y is linear on a logarithmic scale, in which d is the depth of flow, y is the distance above the bed to a point, and C_y is the concentration at y [2]. Fig. 3.1 shows a typical linear variation in concentration profile with particle size.

Maximum instantaneous deviations from mean concentration values are to be found in streams where the suspended sediment consists largely of sand. In contrast, minimum deviations from mean concentration values occur in streams where the suspended sediment consists largely of silt and clay.

Effect of Viscosity on Transport

Water temperature is an important environmental factor affecting the transport of bed material load through its effect in the fall velocity of the particles. As water temperature decreases, the suspended load concentration increases [4]. Large amounts of washload may also have the same effect as decreasing temperature, as demonstrated by field and laboratory studies [5,6] that show a decrease in the fall velocity of the bed material load as the amount of washload increases.

Lateral Distribution of Suspended Sediment

The lateral distribution of suspended sediment at a stream cross section varies with velocity and depth, channel alignment, bed form, and inflow from immediate upstream tributaries. When the suspended sediment is measured at the centroids of sections of equal water

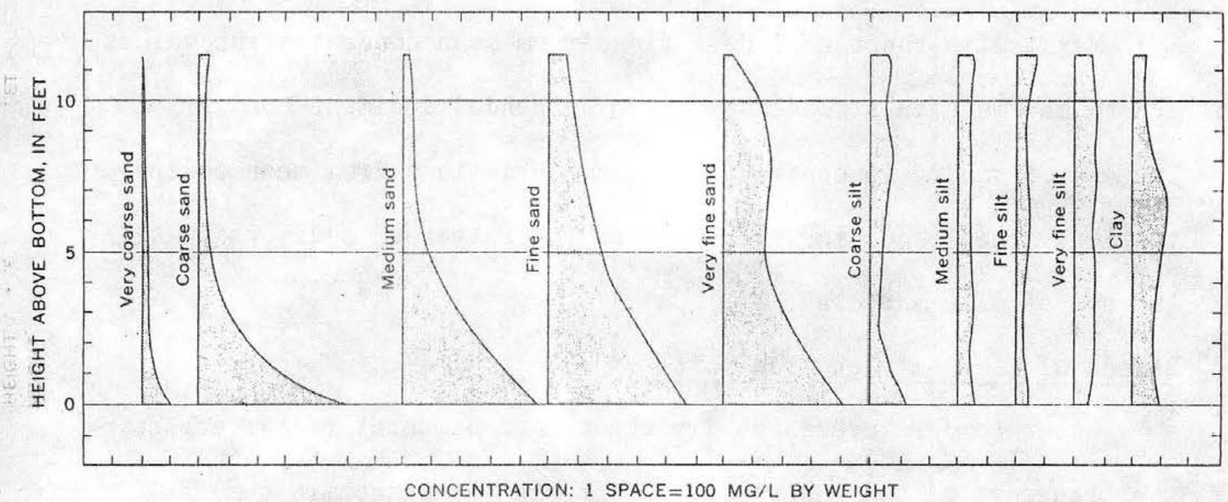

Figure 3.1. Discharge-weighted concentration of suspended sediment for different particle-size groups at a sampling vertical in the Missouri River at Kansas City, Mo., [3].

discharge, the average of the concentrations for the stream verticals is taken as the sediment concentration in the cross section.

Fig. 3.2 shows the relative variation of sediment concentration at selected stream verticals of Missouri River near Omaha, Nebraska.

3.1.1 Sediment Sampling Equipment

The equipment for sediment sampling can be classified into the following:

1) Suspended sediment samplers, of the types: a) depth-integrating, b) point-integrating, and c) single-stage.

2) Bed material samplers, of the types: a) hand-held piston, and b) cable-and-reel rotary bucket.

3) Bedload samplers.

Sediment samplers are well documented in the literature [8]. The following is a brief description of the equipment more likely to be used in sediment studies in strip-mined watersheds.

Depth-Integrating Samplers

Depth-integrating samplers are designed to accumulate a water-sediment sample as they are lowered to the stream bed and raised to the surface at a uniform rate. During transit, the velocity in the nozzle at the point of intake is nearly equal to the local stream velocity.

Two lightweight hand samplers can be used to obtain suspended sediment samplers by wading in a stream. The smallest of the two is designated DH-48, and shown in Fig. 3.3. The sample is collected through the intake nozzle and discharged to a pint glass milk bottle. The sampler, including the container weighs 4 1/2 lbs, and is able to sample to within 3 1/2 inches of the stream bed, [9].

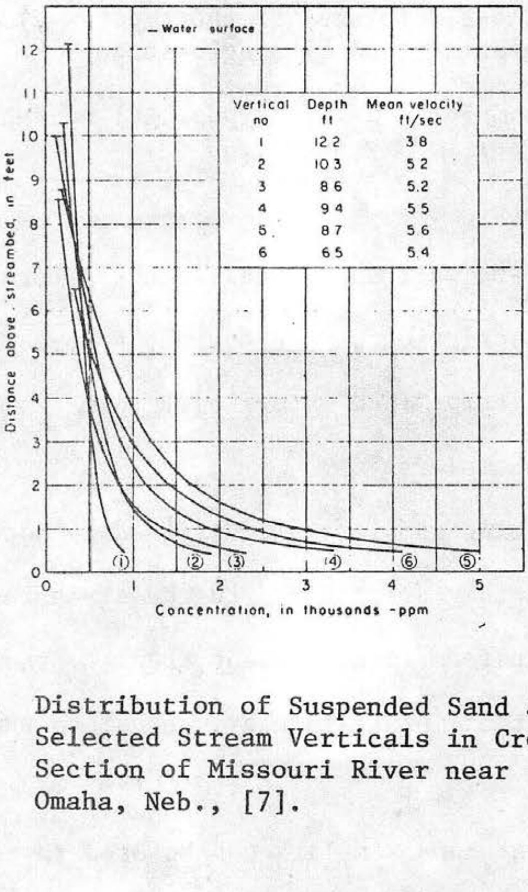

FIG. 3.2. Distribution of Suspended Sand at Selected Stream Verticals in Cross Section of Missouri River near Omaha, Neb., [7].

The other lightweight sampler, designated DH-59, is shown in Fig. 3.4. It weighs about 24 lbs, and is used in streams too deep to be waded. Because of its light weight, it is limited to streams with velocities of less than 5 fps. The sampler will not transverse closer than about 4 inches from the stream bed, [10].

The D-49 sampler with cable suspension is designed for use in streams beyond the range of the hand-operated equipment. It weighs 62 lbs, and it is lowered at a uniform transit rate by controlling the rate of movement of the sampler by a hand-operated reel, [9].

Point-Integrating Samplers

Point-integrating samplers are designed to accumulate a water-sediment sample that is representative of the mean concentration at any selected point in a stream during a short interval of time. They are also used for depth-integration in streams that are too deep to sample in a round trip integration. In depth-integration with a point-integrating sampler, sampling can start at any depth and continue in either an upward or downward direction for a maximum vertical distance of about 30 ft. A rotary valve that opens and closes the sampler is operated by a solenoid energized by batteries at the surface.

The point-integrating samplers in current use are the P-46 (100 lbs), P-61 (100 lbs) and P-63 (200 lbs) [9,10]. All the point samplers are designed for suspension with a steel cable having an insulated inner conductor core. By pressing a switch located at the operator's station, the current may be supplied to the solenoid in the sampler head by storage batteries connected in series to produce 24 or 48 volts.

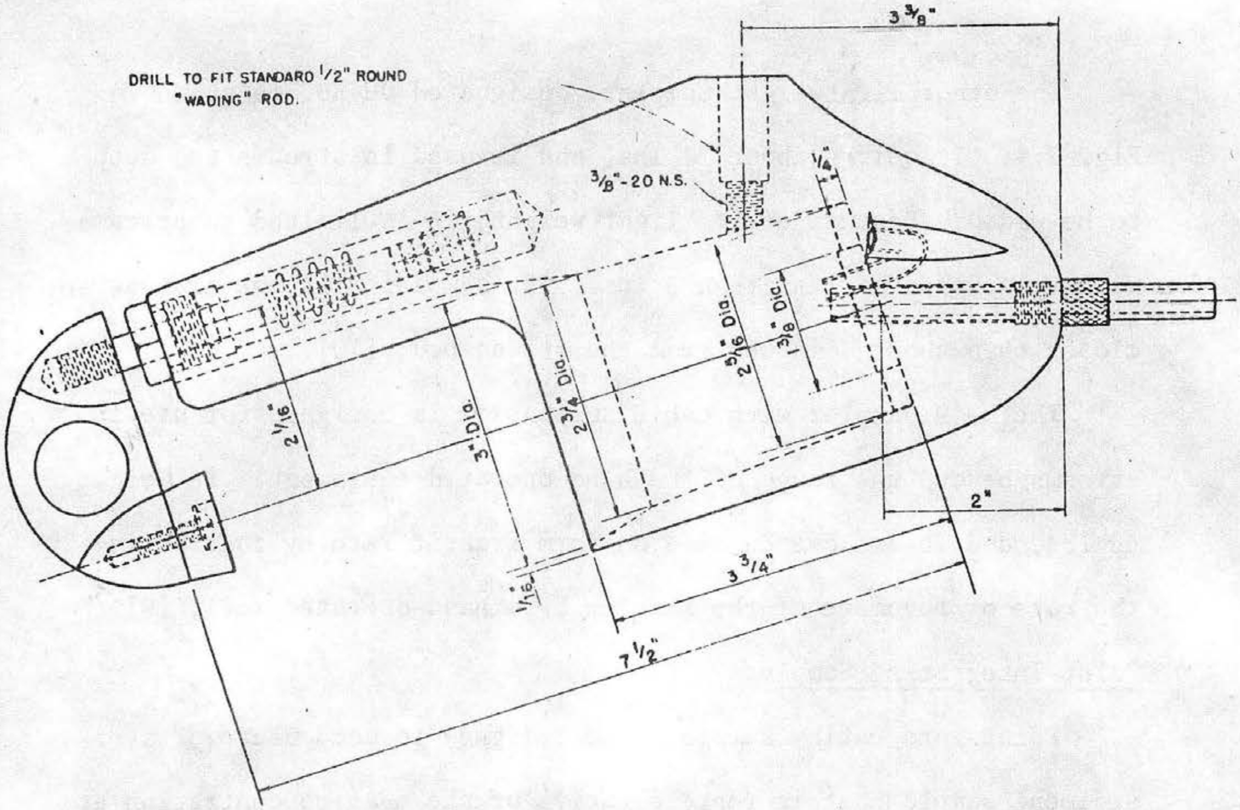

FIG. 3-3. US DH-48 Depth-Integrating Suspended-Sediment Sampler [9].

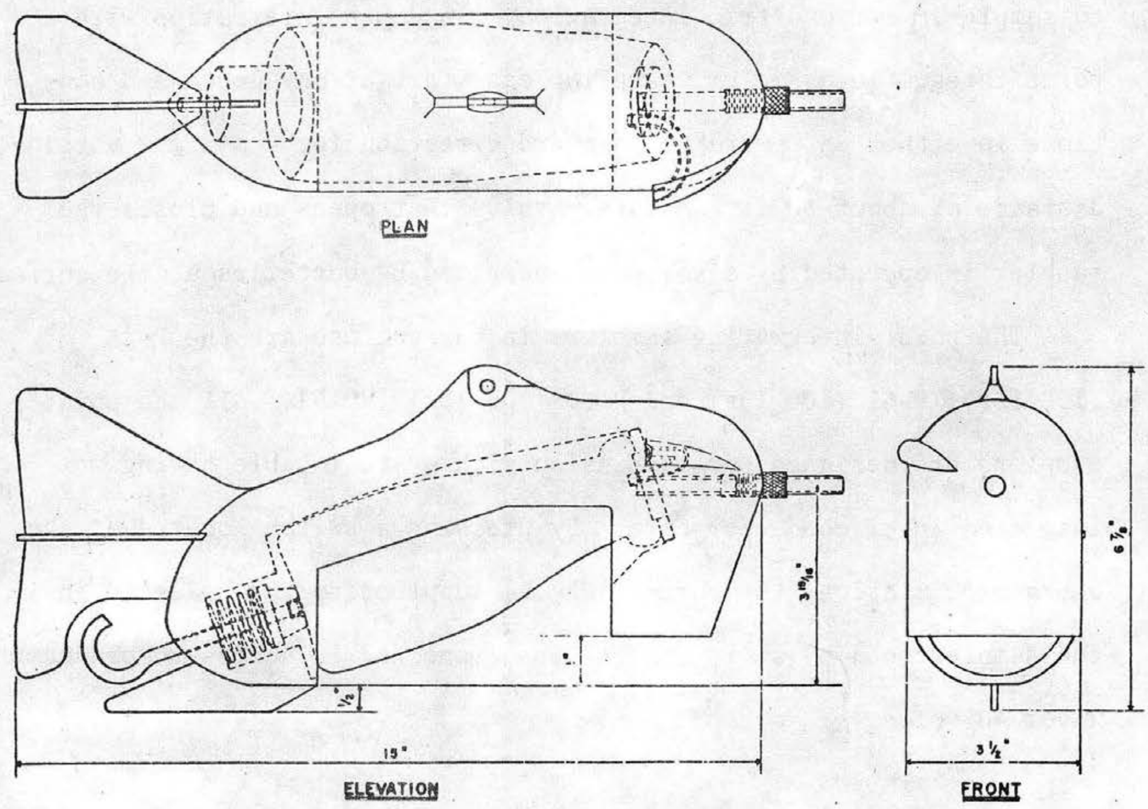

FIG. 3-4. US DH-59 Depth-Integrating Suspended-Sediment Sampler [10].

Single Stage Samplers

The single-stage sampler U-59, was developed to meet the needs for an instrument that would obtain some sediment data on small fast-rising streams where it is impractical to use a conventional depth-integrating sampler. The U-59 sampler is shown in Fig. 3.5.

The basic sampling operation with a single-stage sampler follows [11]. As the water surface rises to the elevation of the intake nozzle, the water-sediment mixture enters. When the water surface elevation reaches C (Fig. 3.5), flow starts over the weir of the siphon, and begins to fill the sample bottle under the head AC. Filling continues until the sample rises to F in the bottle. When the stream rises to D, air is trapped in the air exhaust. As long as sufficient air remains in the tubes, no flow can pass through to alter the original sample.

The U-59 is a type of point sampler because it is positioned in a single point in the stream. Its primary purpose is to collect a sample automatically, and due to its low cost, several of them can be used at different elevations or times during a rising hydrograph.

A significant limitation of the single-stage sampler is that it does not take into account the vertical distribution of suspended sediment. Theoretical adjustments must be made to the data in order to estimate the suspended sediment discharge.

Bed Material Samplers

Three bed material samples are in current use for sampling stream bed material composed primarily of sand or sand and gravel mixture [10]. The BMH-53 sampler is designed to sample the bed of wadable

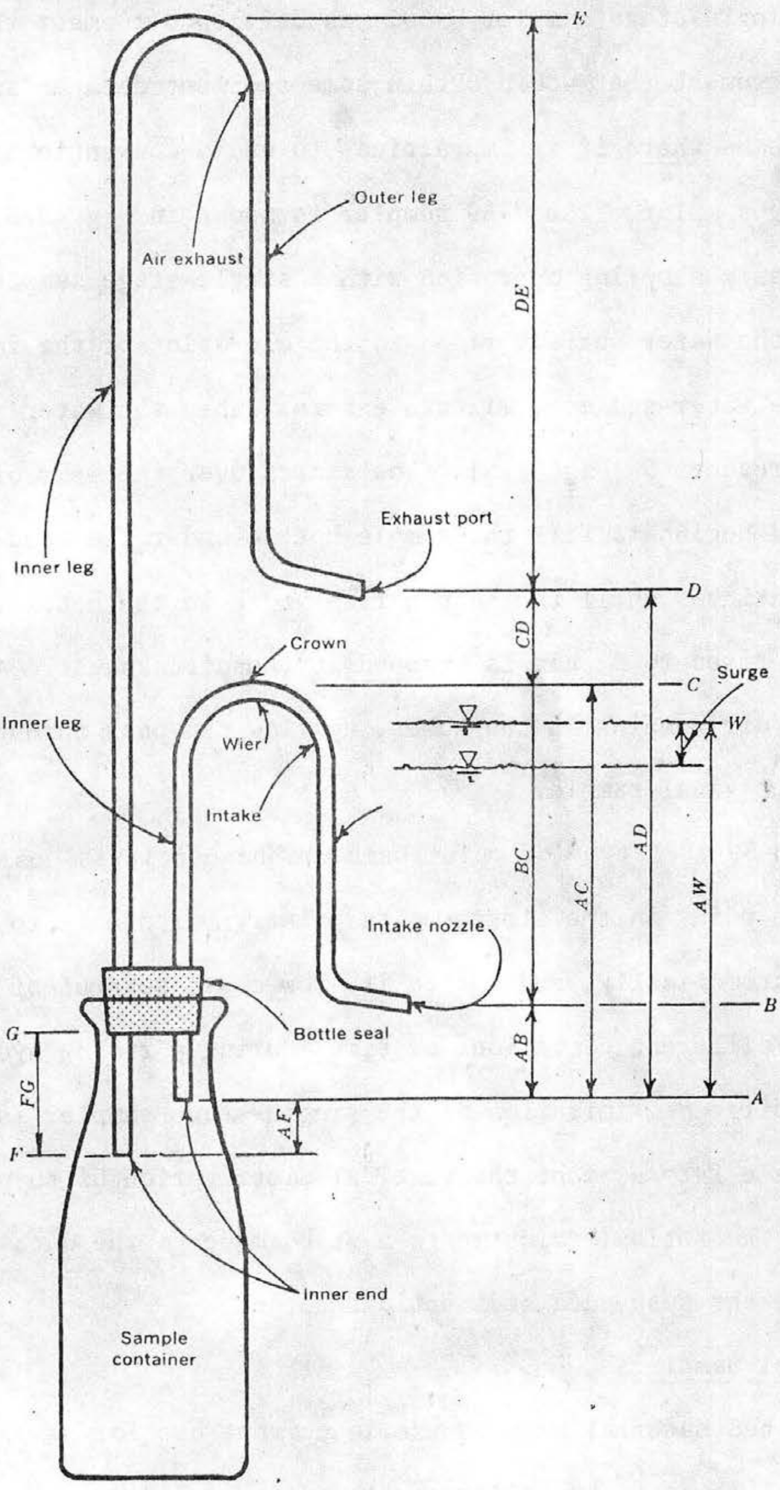

FIG. 3.5. Single-stage suspended sediment sampler U-59 [11].

streams. The instrument is 46 inches long and made of corrosion resistant materials. The collecting end of the sampler is a stainless steel thin-walled cylinder 2 inches in diameter and 8 inches long with a tight fitting brass piston. The piston creates a partial vacuum above the material being sampled, which retains the sample in the cylinder while the sampler is being removed from the bed.

The BM-54 bed material sampler (100 lbs) is designed to be suspended from a cable and to scoop up a sample of the bed sediment 3 inches wide and 2 inches deep. The BMH-60 bed material sampler is similar to the BM-54, but was developed for both handline and cable suspension. It is used to collect samples in deep streams of low velocities.

Bed Load Samplers

Bedload transport is difficult to measure because a device placed at or near the stream bed will necessarily disturb the flow and alter the rate of bedload movement. Various types of bedload samplers have been developed [12], but as yet none of them is reliable, economical and easy to use. The bed load samplers developed in the United States have been closely associated with individual project studies. The samplers have been classified according to their type as a) basket, b) pan, and c) pressure difference. Maximum trap efficiency is about 70% for the best designed pressure difference type [13]. In sand bed streams the measurement of bed load may not be crucial to determine the total sediment load. In these streams, especially with depths of flow of a few feet or deeper, most of the sediment load is carried in suspension and can be directly sampled. The load in the unmeasured zone including the bed load, is then estimated from sediment transport theories described later in this chapter.

3.1.2 Sediment Sampling Techniques

This section covers the various techniques that are available in using the sediment sampling equipment to obtain data on suspended sediment discharge on an alluvial stream.

Selection of Sampler

The stream flow depth and velocity and the facilities at the sampling site (bridge, cable-way, etc.) determine which sampler should be used at a station. Stream depth determines whether hand samplers such as the DH-48 or the BMH-53 or cable suspended samplers such as the D-49 or the P-61 should be used. Depths over 15 ft require the use of point-integrating samplers to avoid overfilling. When the product of depth in feet and velocity in feet per second exceeds ten, the stream may not be wadable. The larger this product, the heavier the sampler required. Considerable experience may be necessary to determine which sampler is best for a given stream condition.

Number of Sampling Verticals

The number of sampling verticals depends on the accuracy being sought and on the variation of sediment concentration across the stream. For streams with a stable cross section and a rather uniform sediment concentration across the width, sampling at a single vertical will usually be adequate.

Depth-integrating samplers will produce a discharge-weighted mean concentration, which can be measured in ppm and converted to mg/l. The measured suspended sediment discharge is given by the following formula:

$$Q_s = Q_w C_s K \qquad (3.1)$$

where Q_s = sediment discharge in tons/day.

Q_w = water discharge in cfs.

C_s = discharge-weighted mean concentration in mg/l.

K = a constant equal to 0.0027.

There are two methods to measure sediment discharge in a stream: a) the method of centroids-of-equal-discharge increments (EDI), and b) the method of equally spaced verticals across the stream and an equal-transit-rate (ETR) at all verticals.

The EDI Method

The EDI method, in which samples are obtained at the centroids of equal discharge increments, is usually limited to streams with stable channels. The method requires an advance knowledge of the streamflow distribution in the cross section before sampling verticals can be selected. If such knowledge is available, the EDI method requires fewer verticals than the ETR.

To make the EDI measurement, it is necessary to determine first the total discharge of the stream in increments across the channel. This enables the determination of the areas of equal discharge for the number of verticals selected, and the measuring vertical is positioned in the centroid of each area of equal discharge. At each measuring vertical, two or more bottles are taken by the depth-integrating method to represent two or more cross-section samples. Laboratory procedures can be considerably simplified if the bottles constituting one cross-section samples have nearly the same quantity of water-sediment mixture, in which case the total sample can be composited.

Obviously, for sand bed streams and for new sediment measuring sites, a water discharge measurement must precede the sediment discharge measurement. It may be possible, however, to estimate the location of the centroids of equal area, albeit if only as an expedient approximation to the actual sediment discharge.

The ETR Method

A cross-sectional suspended sediment sample obtained by the ETR method requires a sample volume proportional to the amount of flow at each of several equally spaced verticals in the cross section. This equal spacing between verticals across the stream and an equal transit rate, both up and down in all verticals, yields a gross sample proportional to the total streamflow. This method is most often used in shallow or sandbed streams where the distribution of water discharge in the cross section is not stable.

The number of sampling verticals for an ETR sediment discharge measurement depends on the streamflow and sediment characteristics as well as on the desired accuracy of the results. Fig. 3.6 shows a nomograph to determine the number of

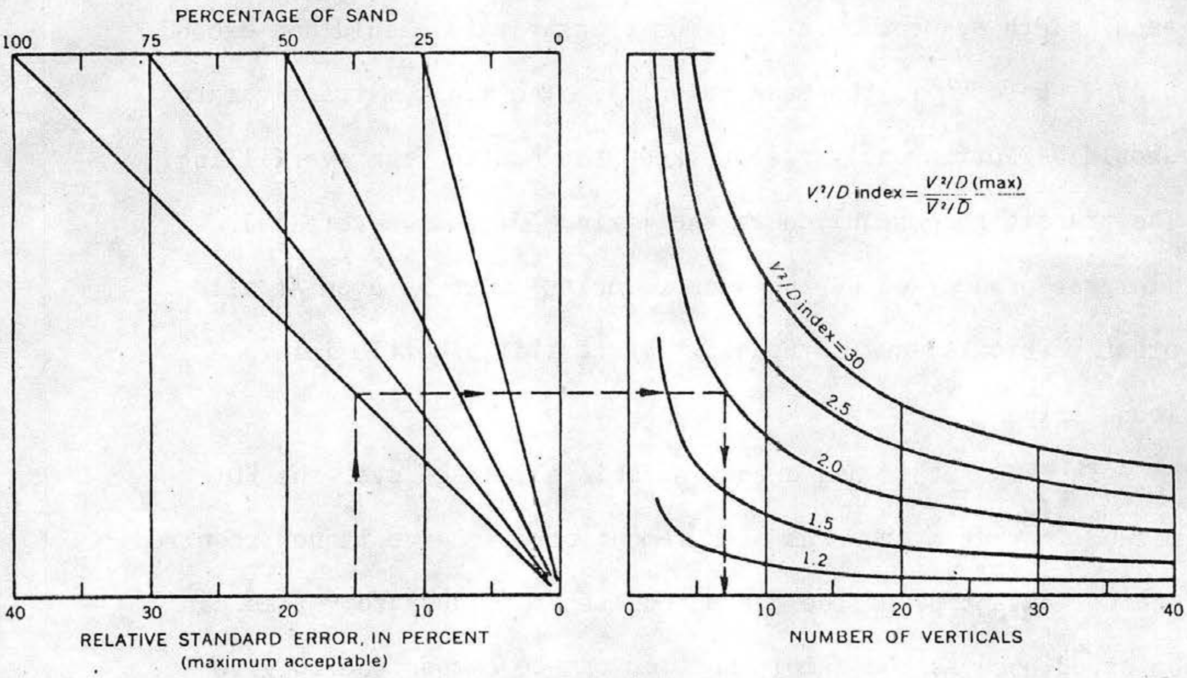

FIG. 3.6. Nomograph to determine the number of sampling verticals required to obtain results within an acceptable relative standard error based on the percentage of sand in the sample and the V^2/D index. Best results are obtained when V is between 2 and 5 fps and D is greater than 1.5 feet, [14].

verticals for a maximum specified error, the percentage of sand in the sample, and the concentration variability expressed as an index (in the calculation of the V^2/D index, $(V^2/D)_{max}$ is the maximum ratio of velocity square to depth among all verticals, and $\bar{V}^2/\bar{D}$ is the ratio of mean velocity square to mean depth of the cross section).

The stream width is divided by the selected number of verticals, and each vertical is positioned in the middle of each width segment. The maximum transit rate should not exceed $0.4V_m$, where V_m is the mean velocity. The minimum transit rate should be sufficiently fast to keep the bottle from overfilling. The transit rate required at the maximum discharge vertical (largest product of depth times velocity) must be used at all other verticals, and is usually set to fill a bottle in a round trip.

The ETR method has a considerable advantage over the EDI method in that a previous measurement of discharge is not required. Another advantage of the ETR method is that laboratory time can be saved because the sample bottles can be composited to give one cross-sectional sediment concentration and particle size gradation.

Sample Timing

For many streams, the largest sediment loads occur during spring runoff. The frequency of suspended sediment sampling should increase during periods of high runoff. During some parts of this period, hourly or bihourly sampling may be required to define the sediment concentration accurately. During the remainder of the year, the sampling frequency could be daily or even once a week.

In general, sediment measuring stations may be operated on a daily, weekly, monthly, or on an intermittent schedule. The more precise the record, the more costly it is, and decisions as to sampling schedule should be taken on the basis of the cost of obtaining the data v. its desired accuracy.

3.1.3 Sediment Yield from Stream Measurements

Sediment yield can be obtained from stream measurements if the unmeasured sediment discharge can be accounted for. The Colby method [15] and the Modified Einstein Procedure [16] enable the computation of the unmeasured sediment discharge. Both methods are based on the same stream measurements, and only the Colby method (1957) will be treated here due to its relative simplicity as compared to the Modified Einstein Procedure. Computer programs for determing the total sediment load by the Modified Einstein Procedure are available elsewhere [17].

Mean velocity, width, average depth and the measured suspended sediment concentration C_s' are required in the Colby method (1957). The procedure to follow is:

1) From Fig. 3.7 obtain an estimate of the unmeasured sediment discharge, in tons per day per foot of width, based on the mean velocity.

2) From Fig. 3.8 obtain a value of the relative suspended sediment concentration, based on mean velocity and depth.

3) Calculate the availability ratio dividing the measured concentration, C_s' by the relative concentration, both in ppm.

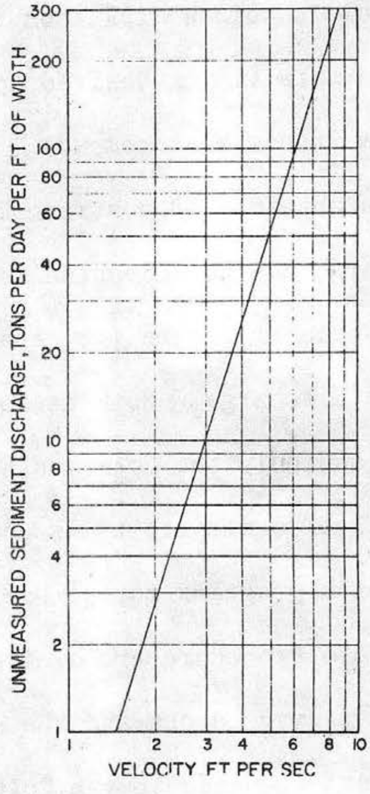

FIG. 3.7. Colby's (1957) Graph of Unmeasured Sediment Discharge against Mean Velocity.

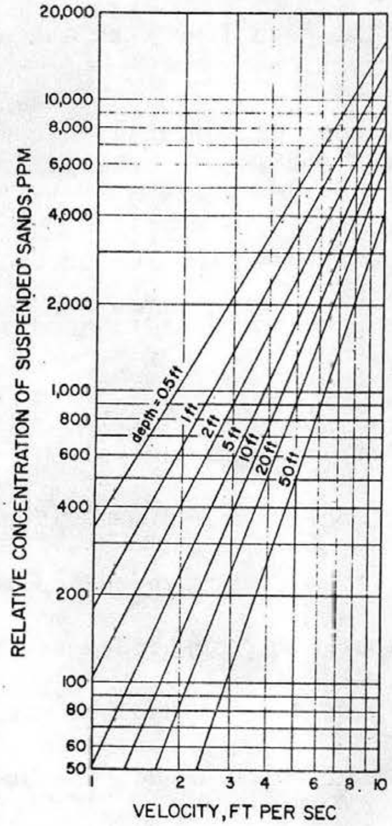

FIG. 3.8. Colby's (1957) Chart of Relative Concentration against Mean Velocity.

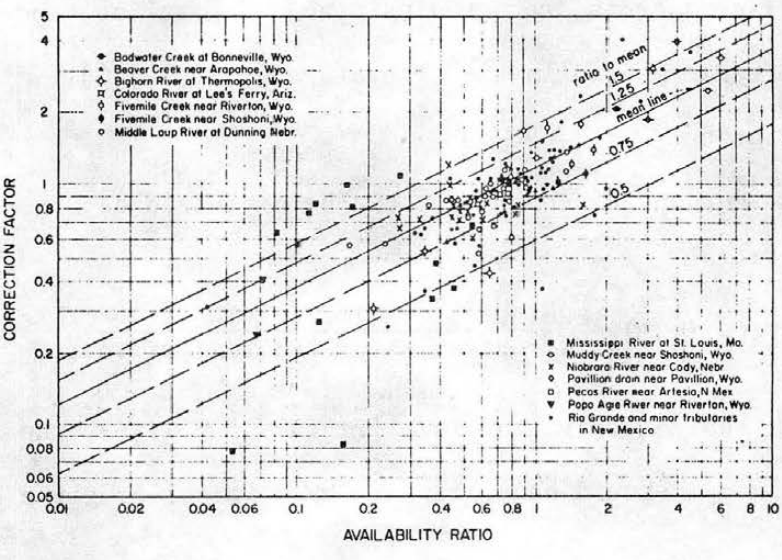

FIG. 3.9. Colby's (1957) Chart of Availability Ratio against Correction Factor.

4) Enter Fig. 3.9 to the mean line with the availability ratio, to determine a correction factor.

5) The unmeasured sediment discharge is the product of the estimated unmeasured sediment discharge from step 1) times the correction factor from step 4), times the channel width.

The total sediment discharge is the sum of the measured sediment discharge (from C_s') and the unmeasured sediment discharge (from Colby's (1957) method).

3.2.0 Laboratory Methods for Sediment Analysis

The two principal functions of a sediment laboratory are to determine: a) the concentration of suspended sediment samples, and b) the particle size distribution of suspended sediment or bed material. Other determinations may include the amount of organic matter, the specific gravity of solids, and the specific weight of deposits.

This section on laboratory methods for sediment analysis includes a brief description of the following: a) determination of concentration, and b) determination of particle size distribution. The procedures outlined herein are based on standard practice, and have been extensively documented in the literature [1,18,19,20].

3.2.1 Concentration

Suspended sediment concentration can be expressed as:

$$\text{Concentration (ppm)} = \frac{\text{weight of sediment} \times 10^6}{\text{weight of water sediment mixture}}$$

To express the concentration in milligrams per liter, the concentration in ppm should be multiplied by a factor A, given in Table 3.1.

Each of several methods for separating sediment from the water in a sample has its advantages and disadvantages. The two most commonly used are: a) evaporation, and b) filtration. The evaporation method is used when the sediment concentration of samples excedes 2000-10000 mg/1. The lower limit applies when the sample consists mostly of fine material, and the upper limit when the sample is mostly sand. The filtration method works best for lower concentrations.

Filtration Method

The filtration method utilizes a Gooch crucible with one of several suitable types of filter material. The crucible is a small porcelain cup of approximately 25 ml capacity with a perforated bottom that is easily adapted or connected to a vacuum system. Usually the sediment is allowed to settle to the bottom of the sample bottle, the supernatant liquid is decanted, the water is filtered out of the remainder as the sediment is washed onto the filter, and then the crucible is dried in an oven, cooled in a desiccator, and weighed.

A commercial glass-fiber filter disk is satisfactory for most types of sediment. For some fine-grained sediments, a glass-fiber disk in conjunction with an asbestos mat may be necessary. The crucible with this extra mat is prepared by placing the glass-fiber disk in the crucible while vacuum is applied and then pouring an asbestos slurry on top of the disk, also while vacuum is applied. The somewhat coarse asbestos mat retains much of the sediment that would ordinarily clog the glass-fiber disk.

When the filtration method is used to determine suspended sediment concentration, a small amount of very fine sediment may be lost in the filtrate. Tests to determine the relative amount of sediment lost in the filtrate seldom show losses more than 5 percent for river samples, even those composed mostly of clay [7].

Evaporation Method

The evaporation method offers some advantages in simplicity of equipment and technique over the filtration method. In the evaporation method, the sediment is allowed to settle to the bottom of the sample bottle, the supernatant liquid is decanted, the sediment is washed into an evaporating dish and then dried in an oven. The settling is accomplished by allowing the container to sit undisturbed for several hours or days, unless the sample contains naturally dispersed clay that requires special flocculating agents to decrease the settling time.

The natural dissolved solids in the supernatant liquid at the bottom of the sample container are retained with the dried sediment, and must be substracted to determine the weight of sediment. The following may be used as a guide to determine if a correction for the weight of dissolved solids is necessary: a 5 percent improvement in the results of concentration of sediment will be realized when the dissolved solids is equal to the sediment concentration, assuming that an aliquot of 5 percent of the native water has been used in the evaporation.

3.2.2 Particle Size Distribution

Particle size usually needs to be defined in terms of the method of analysis. Large sizes, including boulders and cobbles, are measured directly. Intermediate sizes such as gravel and sand are measured semidirectly by sieving. Small sizes, including fine sands, silts and clays, are measured indirectly by sedimentation techniques, i.e., by observing their settling characteristics in water. The sedimentation methods most commonly used are the pipet, the bottom-withdrawal (BW) tube and the visual accumulation (VA) tube. All of these methods will be treated in detail in the following paragraphs.

Amount of Sample

A sample containing silt, clay and coarser material will often require analysis by two or more methods because of the limitation on the range of sizes that can be analyzed by a given method. A sample of coarse bed material may require sieving down to 2mm, analysis of the finer sands by VA tube, and pipet analysis of the finer fraction. Table 3.2 gives a guide to the range of sizes, analysis concentration, and weight of sediment for the sieves, VA tube, pipet and BW tube, and should facilitate decisions on how many sample bottles are needed, how much splitting is required, or which methods are best to use for a given stream and sample.

Organic materials found in some samples can be removed by adding 5 ml of 6 percent solution of hydrogen peroxide for each gram of dry sample in 40 ml of water. It must be stirred thoroughly and covered from 5 to 10 minutes. Large fragments of organic material may then be skimmed off, if it can be assured that they are free of sediment particles. If oxidation is slow the mixture is heated to 93°C, stirred occasionally,

TABLE 3.2. Recommended Size Range, Analysis Concentration, and Quantity of Sediment for Commonly Used Methods of Particle Size Analysis [1].

Method of Analysis (1)	Recommended Size Range, in Millimeters (2)	Desirable Range in Analysis Concentration in milligrams per liter (3)	Range, in optimum Quantity of Sediment, in grams (4)
Sieves	0.062-32	---	0.05[a]
VA Tube[b]	0.062-2.0	---	0.05 - 15.0
Pipet	0.002-0.062	2,000-5,000	1.0 - 5.0
BW Tube[c]	0.002-0.062	1,000-3,500	0.5 - 1.8

[a]Based on use of 3-in. diam sieves and a median size of 0.5 mm or less.

[b]See Table 3.3 for more detail.

[c]If necessary, may be expanded to include sands up to 0.35 mm, the accuracy decreasing with increasing size-the concnetration and size increased accordingly.

TABLE 3.3 Guide to Size Selection of VA Tube [1].

Settling Tube		Sample Size		
Length, in centimeters (1)	Diameter, in millimeters (2)	Dry weight, in grams (3)	Volume, in milliliters (4)	Approximate maximum particle size, in millimeters (5)
120	2.1	0.05- 0.8	0.03-0.5	0.25
120	3.4	0.04- 2.0	0.2 -1.2	0.40
120	5.0	0.8 - 4.0	0.5 -2.4	0.60
120	7.0	1.6 - 6.0	1.0 -4.0	1.00
180	10.0	5.0 -15.0	3.0 -9.0	2.00

and more hydrogen peroxide solution added as needed. After the reaction has stopped, the sediment must be carefully washed with distilled water.

Indirect Measurement

The indirect measurement of particle size distribution involves the determination of the fall velocity, from which a theoretical fall diameter may be obtained. The fall velocity-fall diameter concept provides a desirable expression of the hydraulic characteristics of the very large number of particles in a water sample.

Particle size analyses by sedimentation methods should be carried out in such a way that flocculation of the clay particles is minimized. To accomplish this, the native water is removed from the sample as completely as possible. Then the sample is washed into a dispersion cup, diluted to about 300 ml with distilled water, mixed for 5 min in a soil mixer, poured over a 230 mesh sieve, and washed with distilled water to separate the sand from the silt and clay. 1 ml of dispersing agent must be added for each 100 ml of the desired suspension. The dispersing agent is usually made by dissolving 35.70 g of sodium hexametaphosphate and 7.94 g of sodium carbonate in distilled water and diluting to one liter volume [1].

VA Tube Method

The visual accumulation tube is a fast, economical, and reasonably accurate means of determining the size distribution of a sediment sample, in terms of the fall velocity or fall diameter. It is specially adapted for samples composed of sand. The fine material is removed by either wet sieving or by sedimentation methods, and analyzed by either the pipet or BW method.

Equipment for the VA tube method of analysis consists primarily of the special settling tube and the recording mechanism. As shown in Fig. 3.10 the device consists of 1) a glass funnel with a stem about 25 cm long; 2) a rubber tube connecting the funnel and the main settling tube; 3) a manual pinch valve; 4) removable glass settling tubes each having a different-sized collector at the bottom; 5) a tapping mechanism that strikes against the glass tube to keep the accumulation of sediment uniformly packed; 6) a special recorder consisting of a chart cylinder that rotates at a constant rate; 7) a tracking carriage with the recording pen and an optical instrument for locating the surface of the accumulation; and 8) a recorder chart that is a printed form incorporating the fall diameter calibration.

The VA tube method uses the stratified system of settling as contrasted with the dispersed system of the pipet or the BW tube. The stratified system is one in which the particles start falling from a common source and become stratified according to their settling velocities as they are deposited. At a given instant, the particles coming to rest at the bottom of the tube are of one "sedimentation size" and are finer than particles that have previously settled out and coarser than those remaining in suspension [21,22].

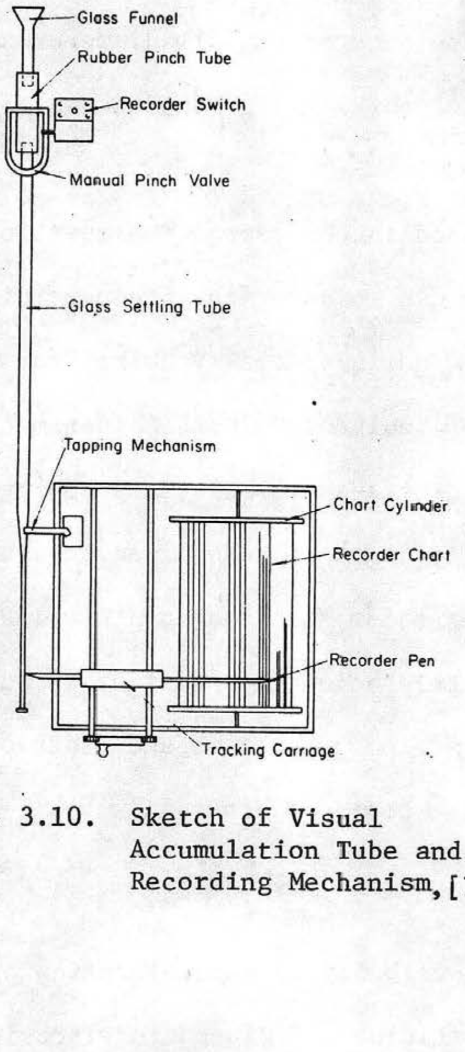

FIG. 3.10. Sketch of Visual Accumulation Tube and Recording Mechanism,[7].

Results from the VA tube are best if the total height of accumulation in the bottom of the tube is between 4 cm and 12 cm. Table 3.3 gives a guide to the appropriate size of VA tube on the basis of sample weight, volume, and maximum particle diameter.

The VA tube analysis results in a continuous pen trace of the depth of sediment deposited as a function of time. The chart is calibrated so that, for a given temperature, the relative amount of each size in terms of fall diameter and percentage finer can be determined with a graduated scale.

Pipet Method

The pipet method is considered the most reliable indirect method for routine use to determine the particle size gradation of fine sediments, and is specially suited for samples having very small quantities of sediment. In the pipet method, a concentration of a quiescent suspension at a predetermined depth as a function of settling time, is determined. Particles having a settling velocity greater than that of the size at which separation is desired will settle below the point of withdrawal after elapse of a certain time. The time and depth of withdrawal are predetermined on the basis of Stokes law:

$$w = \frac{gd^2}{18\nu} \frac{\gamma_s - \gamma}{\gamma} \tag{3.2}$$

where w = settling velocity, g = acceleration of gravity, d = diameter of particle, ν = kinematic viscosity of the liquid, γ_s = specific weight of sediment, and γ = specific weight of liquid.

Table 3.4 gives recommended times and depths of withdrawal to determine concentrations of sediment finer than each of six sizes for a range of water temperatures.

Various types of pipet equipment have been developed . The pipet equipment described by Krumbein and Pettijohn [23] is satisfactory when only relatively few samples are analyzed. To facilitate the analysis of many samples, the apparatus shown in Fig.3.11 has been developed [7]. A movable carriage containing the pipet assembly is moved so that it enables pipetting from several sedimentation cylinders.

Attached to the right stem of the three-way stopcock is an inverted Y-shaped glass tube. A length of rubber tubing, with a pressure bulb at one end, is attached to the top stem of the Y. A length of rubber tubing is attached to the short stem of the Y connecting the apparatus to a distilled water supply with a head of about 1.5 meters. The flow of distilled water is controlled by a stopcock.

After the sample is drawn into the pipet, the three-way stopcock plug is rotated 180°, and the sample is allowed to drain freely into an evaporating dish. To insure complete removal of all sediment in the pipet, the distilled water valve is then opened, and the pipet is washed out from the top. The material in each evaporating dish is dried at 110°C, cooled in a desiccator and weighed.

The net dry weight of the sediment in each pipet withdrawal when multiplied by the volume ratio, total volume of suspension

TABLE 3.4. Time of Pipet Withdrawal for Given Temperature, Depth of Withdrawal, and Diameter of Particles[a].

Temperature, in degrees Celsius	DIAMETER OF PARTICLE, IN MILLETERS					
	0.062	0.031	0.016	0.008	0.004	0.002
	Depth of withdrawal, in centimeters					
	15	15	10	10	5	5
	Time of withdrawal, in minutes and seconds[b]					
(1)	(2)	(3)	(4)	(5)	(6)	(7)
20	44	2 52	7 40	30 40	61 19	4 5
21	42	2 48	7 29	29 58	59 50	4 0
22	41	2 45	7 18	29 13	58 22	3 54
23	40	2 41	7 8	28 34	57 5	3 48
24	39	2 38	6 58	27 52	55 41	3 43
25	38	2 34	6 48	27 14	54 25	3 38
26	37	2 30	6 39	26 38	52 2	3 33
27	36	2 27	6 31	26 2	52 2	3 28
28	36	2 23	6 22	25 28	50 52	3 24
29	35	2 19	6 13	24 53	49 42	3 19
30	34	2 16	6 6	24 22	48 42	3 15

[a] The values in this table are based on particles of assumed spherical shape with an average specific gravity of 2.65, the constant of acceleration due to gravity=980 cm/s^2, and viscosity varying from 0.010087 cm^2/s at 20° C to 0.008004 cm^2/s at 30° C.

[b] Data in Col. 2 are in seconds.

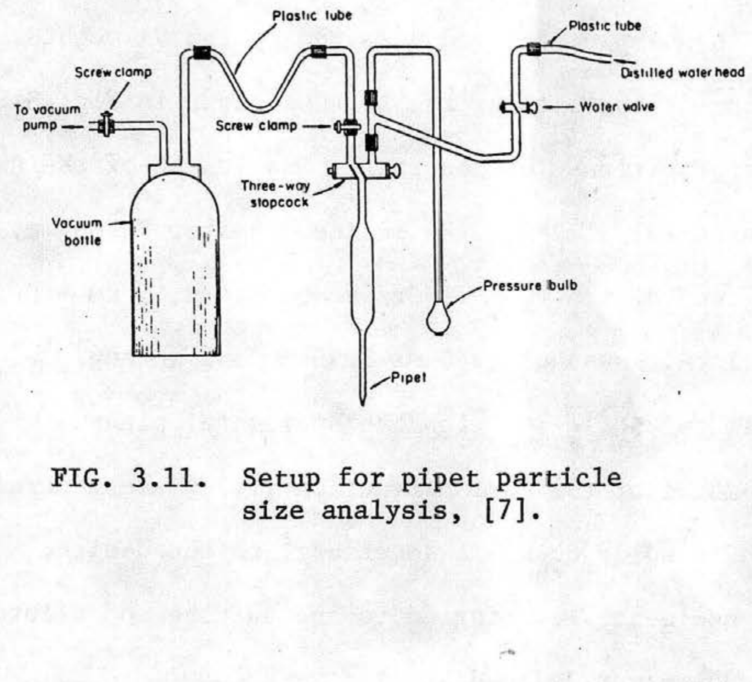

FIG. 3.11. Setup for pipet particle size analysis, [7].

divided by the volume of the pipet, gives the weight of the sediment in the suspension finer than the size corresponding to the time and depth of withdrawal. The latter value, divided by the dry weight of the total sediment in the sample, gives the fraction of total sediment finer than the indicated size.

BW Tube Method

The BW (bottom withdrawal) tube method may be used in laboratories where the pipet equipment is not available or where the samples contain a smaller quantity of fines than recommended for the pipet method. The sand fraction should be removed from the sample [24] and analyzed by the VA method.

The equipment consists of the BW tube shown in Fig. 3.12, with adequate provisions for mounting. The length of the BW tube is approximately 122 cm, the inside diameter 25-26 mm, and the lower end of the tube is drawn down to 6.35 mm $\pm$ 0.25 mm ID with a wall thickness of 1.25 mm-1.75 mm and an angle of tapered portion of 60° $\pm$ 10° with the horizontal plane.

After removal of the coarse fraction [1,20] the remaining fine fraction is split down, if necessary, to the desired 0.5g-1.8g of sediment, transferred to the BW tube and diluted to about the 90-cm mark with distilled water.

Before placing the tube in the rack to start the settling, mild mechanical mixing is accomplished by placing a cork in the upper end of the tube and tilting the bottom of the tube up about 10° from the horizontal. It must be held in this position

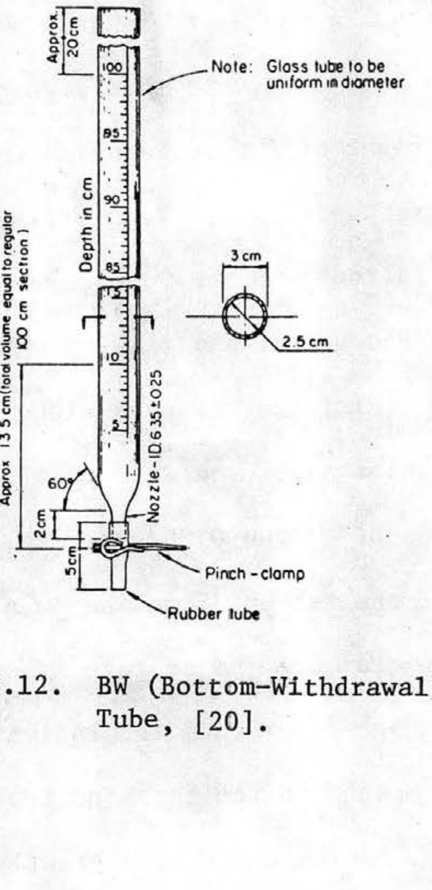

FIG. 3.12. BW (Bottom-Withdrawal) Tube, [20].

and shaken to wash all particles from the nozzle. The air bubble should then be at the nozzle end and all coarse particles should be distributed uniformly along the tube. The tube is inverted from end to end for one minute, whereupon it is turned in an upright position and securely fastened to the stand. Time of settling is begun for the settling process when the bubble starts upward from the bottom.

Equal-volume fractions are usually withdrawn using time intervals chosen in such a way as to best define an Oden curve of the type shown in Fig. 3.13. In this figure, W_1 and W_2 are the percentages by weight of the sediment in the sample that are finer than sizes corresponding to t_1 and t_2, respectively, and obtained by drawing tangents to the Oden curve.

The schedule of the withdrawal times may be determined from Table 3.5 and the fall distance for each withdrawal. The last scheduled withdrawal time should be well past the settling time for definition by tangent of the 0.002-mm size.

The intercept of the tangent from the point indicated by the given size to the ordinate (percentage in suspension) can be read as the percentage finer than the indicate size. Considerable care is needed in the construction of the Oden curve, since the shape of the curve will greatly affect the intercept of the tangent with the percentage scale.

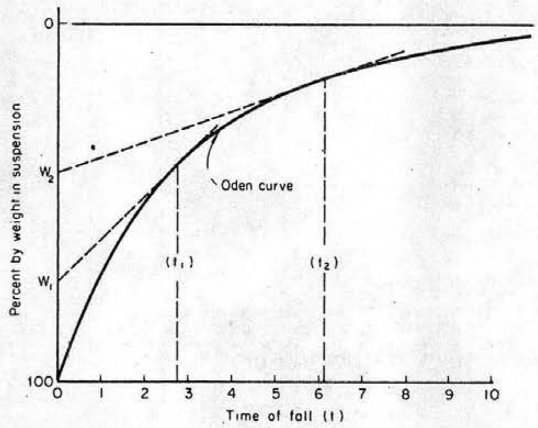

FIG. 3.13. Oden Curve Showing Relative Amount of Sediment Remaining in Suspension with Time; Intersection of Tangent to Curve with Ordinate Represents Percentage by Weight of Sediment in Suspension in Time (t), [1].

TABLE 3.5. Bottom Withdrawal Tube Time of Settling to Be Used with ODEN Curve[a]

Temperature, in degrees Celsius (1)	Particle Diameter, in millimeters 0.25 (2)	0.125 (3)	0.0625 (4)	0.0312 (5)	0.0156 (6)	0.0078 (7)	0.0039 (8)	0.00195 (9)
18	0.522	1.48	5.02	20.1	80.5	322	1,288	5,154
19	0.515	1.45	4.88	19.6	78.5	314	1,256	5,026
20	0.508	1.41	4.77	19.2	76.6	306	1,225	4,904
21	0.503	1.39	4.67	18.7	74.9	299	1,198	4,794
22	0.497	1.37	4.55	18.3	73.0	292	1,168	4,675
23	0.488	1.34	4.45	17.8	71.3	285	1.141	4,566
24	0.485	1.32	4.33	17.4	69.6	279	1,114	4,461
25	0.478	1.30	4.25	17.0	68.1	273	1,090	4,361
26	0.472	1.28	4.15	16.7	66.6	266	1,065	4,263
27	0.467	1.26	4.05	16.3	65.1	260	1,042	4,169
28	0.462	1.24	3.97	15.9	63.7	255	1,019	4,079
29	0.455	1.22	3.88	15.6	62.3	249	997	3,991
30	0.450	1.20	3.80	15.3	61.0	244	976	3,907
31	0.445	1.18	3.71	14.9	59.7	239	956	3,825
32	0.442	1.17	3.65	14.6	58.5	234	936	3,747
33	0.438	1.15	3.58	14.2	57.3	229	917	3,671
34	0.435	1.38	3.51	13.9	56.1	224	898	3,494

[a]Time in minutes required for spheres having a specific gravity of 2.65 to fall 100 cm in water at varying temperatures.

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Chapter IV

LEGAL ASPECTS OF STRIP MINING

Legal requirements for strip mine reclamation are of a relatively recent origin. The federal government does not have regulations concerning reclamation of strip mined lands to date. For the last five years, the United States Congress has been considering strip mine reclamation regulations. This effort has reached a climax in recent times with President Ford vetoing the "Surface Mining Control and Reclamation Act of 1975" and with Congress upholding the veto [1975].

Although there are no federal reclamation laws in practice there are coal mining operations on both Federal and Indian lands. The coal leases on these lands are summarized in Tables 4.1 and 4.2.

Table 4.1. Coal Leases on Federal Lands

State	Number of Leases	Total Acreage
Alabama	1	200.00
Alaska	5	2,753.14
California	1	80.00
Colorado	111	120,905.56
Montana	17	36,232.27
New Mexico	29	41,038.12
North Dakota	19	16,275.75
Oklahoma	53	87,013.56
Oregon	3	5,403.18
Utah	194	266,632.49
Washington	2	521.09
Wyoming	89	199,701.04
TOTAL	524	776,756.20

Source: U. S. Geological Survey

Table 4.2. Coal Leases on Indian Lands

Leases

1. Peabody Coal Co.:
   Hopi-Navajo (Arizona):
   (a) Hopi-Navajo, 40,000 acres
   (b) Navajo, 24,858 acres
   Southern Ute (southern California), 19,452 acres
   Northern Cheyenne (southeastern Montana), 6 leases, 16,035 acres

2. Utah International, Inc.:
   Navajo (northwestern New Mexico), 31,416 acres

3. Pittsburg & Midway Coal Mining Co.:
   Navajo (westtana), 13,237 acres

4. El Paso Natural Gas Co., and Consolidation Coal Co.:
   Navajo (northwestern New Mexico), 40,287 acres

5. Westmoreland Resources:
   Crow (southeastern Montana), 2 leases, 30,876 acres

6. American Metals Climax:
   Crow (southeastern Montana), 14,237 acres

7. Shell Oil Co.:
   Crow (southeastern Montana), 30,248 acres

Source: Bureau of Indian Affairs

Besides the problem of uncontrolled reclamation operations on Federal and Indian lands there is also the problem of unreclaimed surface mined lands in the States. Most States that are affected with orphan mine land cannot adequately reclaim the land. Thus, they generally seek reclamation funds from the Federal government. Table 4.3 summarizes the surface mined lands that are required by law to be reclaimed and those for which reclamation is not required. This table shows that there is a considerable acreage of orphan mine lands in the United States.

Table 4.4 is an estimate of the total remaining coal reserves in the United States. This is for both surface mining and underground mining. For exploitation of the remaining coal in the United States, the affected land will be on Federal, State and Indian lands.

Thirty-two States at the present time have regulations for coal strip mine reclamation. Of the thirty-two States, six do not have any fossil fuel mining operations. All of these States laws have certain provisions in common, [1].

1) an application for a permit must be filed;
2) the operator is required to post a performance bond to insure compliance with the law;
3) the operator must submit with his application a description of the lands to be mined, and periodic reports on the progress of the operation;
4) the disturbed land must be graded to varying degrees;
5) the disturbed area must be reclaimed within specific time limits;
6) performance bonds held until the state concludes that the reclamation has met the requirements of the law;
7) failure to complete reclamation results in forfeiture of the bond and, in some cases, prohibits the issuance of new permits to the operator involved; and
8) criminal penalties are prescribed for operators without a permit or license.

Table 4.3 Status of Land Disturbed by Coal Surface Mining in the United States and Needing Reclamation as of Jan. 1, 1974, by States.
Source: U.S. Soil Conservation Service

[Acres]

State	Reclamation not required by law	Reclamation required by law
Alabama	57,878	118
Alaska	2,400	
Arizona	150	
Arkansas	9,451	494
California		
Caribbean area		
Colorado	4,687	641
Connecticut		
Delaware		
Florida		
Georgia		
Hawaii		
Idaho		175
Illinois	49,748	20,891
Indiana	2,500	6,000
Iowa	25,650	
Kansas	43,700	2,500
Kentucky	69,000	117,000
Louisiana		
Maine		
Maryland	2,250	3,851
Massachusetts		
Michigan	500	
Minnesota		
Mississippi		
Missouri	75,506	1,250
Montana	300	300
Nebraska		
Nevada		
New Hampshire		
New Jersey		
New Mexico		25,798
New York		
North Carolina		
North Dakota	10,000	200
Ohio	23,926	45,825
Oklahoma	13,858	6,350
Oregon		
Pennsylvania	159,000	33,000
Rhode Island		
South Carolina		
South Dakota	790	
Tennessee	20,500	5,200
Texas	5,470	
Utah	120	
Vermont		
Virginia	18,000	5,014
Washington	471	1,010
West Virginia	25,720	51,560
Wisconsin	234	76
Wyoming	3,078	2,828
Total	621,887	337,081

Table 4.4 Total Estimated Remaining Measured and Indicated Coal Reserves of the United States as of Jan. 1, 1970.[1] Source: "U.S. Energy Outlook, Coal Availability," National Petroleum Council, 1973.

[In beds 28-in and more thick, for bituminous, anthracite, and semianthracite, and 5 ft or more thick for subbituminous and lignite beds--Million tons]

State	Remaining measured and indicated reserves					Total--All Ranks more than 14 in and 3,000 ft overburden	Measured and indicated as percent of total
	Bituminous	Subbituminous	Lignite	Anthracite semi-anthracite	Total		
Alabama	1,731	0	(2)	0	1,731	13,444	12.9
Alaska	667	5,345	(3)	(4)	6,012	130,087	4.6
Arkansas	313	0	(2)	67	380	2,420	15.7
Colorado	8,811	4,453	0	16	13,280	80,679	16.5
Georgia	18	0	0	0	18	18	100.0
Illinois	60,007	0	0	0	60,007	139,372	43.1
Indiana	11,177	0	0	0	11,177	34,661	32.2
Iowa	2,159	0	0	0	2,159	6,513	33.1
Kansas	328	0	0	0	328	18,678	1.8
Kentucky west	20,876	0	0	0	20,876	36,482	57.2
Kentucky east	11,049	0	0	0	11,049	28,850	38.3
Maryland	557	0	0	0	557	1,168	47.7
Michigan	125	0	0	0	125	220	56.8
Missouri	12,623	0	0	0	12,623	23,339	54.1
Montana	862	31,228	6,878	0	38,968	221,698	17.6
New Mexico	1,339	779	0	2	2,120	61,455	3.4
North Carolina	(5)	0	0	0	(2)	110	0
North Dakota	0	0	36,230	0	36,230	350,649	10.3
Ohio	17,242	0	0	0	17,242	41,568	41.5
Oklahoma	1,583	0	0	0	1,583	3,195	49.5
Oregon	(6)	(6)	0	0	(6)	332	0
Pennsylvania	24,078	0	0	12,525	36,603	69,686	52.5
South Dakota	0	0	757	0	757	2,031	37.0
Tennessee	939	0	0	0	939	2,606	36.0
Texas	(6)	0	6,870	0	6,870	12,918	53.2
Utah	9,155	150	0	0	9,305	32,070	29.0
Virginia	3,561	0	0	125	3,686	9,817	37.3
Washington	312	1,188	0	0	1,500	6,183	24.3
West Virginia	68,023	0	0	0	68,023	101,186	67.3
Wyoming	3,975	25,937	(3)	0	29,912	120,684	24.8
Other States	(6)	(6)	46	0	46	4,721	1.0
Total	261,510	69,080	50,781	12,735	394,106	1,556,840	25.3

[1] Figures are reserves in ground, about half of which may be considered recoverable. Includes all beds under less than 1,000 ft of overburden and over 28-in in bed thickness for bituminous and anthracite and 5 ft or more for subbituminous and lignite.
[2] Small reserves of lignite in beds less than 5 ft thick.
[3] Small reserves of lignite included with subbituminous reserved.
[4] Small reserves of anthracite in the Bering River field believed to be too badly crushed and folded to be economically recoverable.
[5] Negligible reserves with overburden less than 1,000 ft.
[6] Data not available to make estimate.

Most of the state legislation is relatively recent. The major legislation for controlling mine land reclamation was the Interstate Mining Compact in 1965. The following nine states are involved in the Compact: Indiana, Kentucky, Maryland, North Carolina, Oklahoma, Pennsylvania, South Carolina, Tennessee, and West Virginia. The general purposes of the Interstate Mining Compact are [1]:

1) advance the protection of restoration of land, water and other resources affected by mining;
2) assist in the reduction or elimination or counteracting of pollution or deterioration of land, water and air attributable to mining;
3) encourage programs in each of the states which will achieve comparable results in protecting, conserving and improving the usefulness of natural resources, to the end that the most desirable conduct of mining and related operations may be universally facilitated;
4) assist the party states in their efforts to facilitate the use of land and other resources affected by mining, so that such use may be consistent with sound land use, public health and public safety and to this end to study and recommend techniques for the improvement, restoration or protection of such land and other resources; and
5) assist in achieving and maintaining an efficient and productive mining industry and increasing economic and other benefits attributable to mining.

With the Interstate Mining Compact each party State must formulate and establish a program for the conservation and use of mined lands by establishing standards, enacting laws, or continuing present laws to accomplish the following purposes:

1) protect the public, adjoining landowners and other landowners from damage to their lands and structures from abandonment and neglect of land property that were used in the operations;
2) abate and control water, air and soil pollution resulting from mining present, past and future; and
3) institute and maintain suitable programs for the adaption, restoration and rehabilitation of mined lands.

The nine states that belong to the Interstate Mining Compact have some of the most complete regulations concerning strip mine reclamation. However, there are other states that have established reclamation laws that are as complete as the Interstate Mining Compact states. Most notably is Montana with perhaps the most stringent reclamation regulations in the United States.

4.1.0. Definitions

The following definitions are used throughout this chapter. The name of the state from which legislation the definition was obtained is indicated for reference purposes. The references are listed at the end of the chapter.

1) Abandoned: an operation where no mineral is being produced and where the state determines that the operation will not continue or resume (Montana).
2) Active Site: a site where strip mining is being conducted (Iowa).
3) Advisory Board: the land rehabilitation advisory board in the state (Iowa).
4) Affected Land: the land within the permit area, from which the overburden is removed and that occupied by the spoil, sediment control structures and all land utilized by the mining operator (Maryland).
5) Back Fill: to place material back into an excavation and return the area to a predetermined slope (West Virginia).
6) Bench: the ledge, shelf, table or terraces formed in the contour method of strip mining (Montana).
7) Bench Width: the width of the bench or terrace as measured from the base of the highwall to the outslope toe of the original terrace or fill bench (Maryland).
8) Box Cut: the first open cut in strip mining which results in the placing of overburden on unmined land adjacent to the initial pit and outside the area to be mined (Oklahoma).
9) Commissioner: the land commissioner serving as the head of the department of public lands (Idaho).
10) Contour Strip Mining: a strip mining method commonly carried out in areas of rough and hilly topography in which the coal or mineral seam outcrops along the side of the slope and entrance is made to the seam by excavating a bench or table cut at and along the site of the seam outcropping with the excavated overburden commonly being cast down the slope below the mineral seam and the operating bench (Montana).

11) Cross Drain: a ditch constructed to carry away excessive drainage from a main collecting point or ditch (West Virginia).
12) Cut: an excavation made by excavating equipment to remove overburden in a single progressive line (West Virginia).
13) Cut-Fill: overburden is removed from an elevated portion of a road, bench or terrace and deposited in a depressed portion in order to maintain a desired grade (Maryland).
14) Degree: from the horizontal, and is subject to a tolerance of 5 percent error (Montana).
15) Deposition of Sediment: placing or causing to be placed in any waters of the state, in stream beds on or off the land described in an application for a strip mining license, or upon other lands, any organic or inorganic matter which settles, or is capable of settling, to the bottom of such waters and onto such beds or lands (Ohio).
16) Direct Seeding: the seeding of seeds by hand sowing, machine sowing, or area-seeding (Alabama).
17) Diversion Ditch: a machine-made waterway used for collecting groundwater or a ditch designed to change the actual or normal course of ground and/or surface water (West Virginia).
18) Face of Coal: the exposed vertical cross section of the natural coal seam or deposit being mined and generally forming the base of the highwall left by excavating operations in strip mining (Maryland).
19) Fill Bench: that portion of a bench or terrace formed by spoil or overburden which has been deposited over the original slope (Maryland).
20) Final Cut: the last pit created in a strip-mined area (Illinois).
21) Gob: that portion of refuse consisting of waste coal or boney coal of relatively large size which is separated from the marketable coal in the cleaning process or solid refuse material, not readily waterborne or pumpable, without crushing (Missouri).
22) High Wall: that side of the pit adjacent to unmined land (Arkansas).
23) Inactive Site: a site where strip mining is not being conducted but where overburden has been disturbed in the past for the purpose of conducting surface mining and an operator anticipates conducting further surface mining operations in the future (Iowa).
24) Key Way: an opening through the fill bench and/or bench for the purpose of drainage or haulage (Maryland).
25) Low Wall: the side of the fill bench facing the highwall (Maryland).
26) Natural Drainway: any water course or channel which carries water to the tributaries and rivers of the watershed. The U.S. Geological Survey classification of perennial or intermittent streams shall be considered as natural drainways (West Virginia).

27) Open Pit Mining: the mining of a mineral in the regular operation of a business by removing the overburden lying above natural deposits thereof and mining directly from the natural deposits thereby exposed or by mining directly from deposits lying exposed in their natural site. It does not include excavation or grading preliminary to a construction project nor borrow operations for highway constructions (Michigan).
28) Operation: all of the premises, facilities, roads, and equipment used in the process of producing coal from a designated strip mine area or removing overburden for the purpose of determining the location, quality or quantity of a natural coal deposit (Kentucky).
29) Operator: any person, firm, partnership, association, or corporation engaged in or controlling one or more strip mining operations (Alabama).
30) Orphan Mine: land affected by strip mining operations prior to the enactment of state laws (Tennessee).
31) Outer Slope: the disturbed area extending from the outer point of the bench to the extreme lower limit of the disturbed land (West Virginia).
32) Overburden: as applied to the strip mining of coal, refers to all of the earth and other materials which lie above natural deposits of coal and includes such earth and other materials disturbed from their natural state in the process of strip mining (Missouri).
33) Peak: a projecting point of overburden created in the strip mining process (Illinois).
34) Pit: a tract of land, from which overburden has been or is being removed for the purpose of open pit mining (Arkansas).
35) Reclamation: the process of backfilling, grading and shaping of the disturbed land in the affected area, constructing water control facilities, the taking of measures to control current or future air, water or soil pollution and the planting of vegetation and other measures; all directed toward placing the affected area in a condition whereby it can serve some purpose, at least as useful as that in existence before any mining (Tennessee).
36) Refuse: all wasted material and debris connected with open pit mining and with mechanical removal, cleaning and preparation of minerals at the mine site (Arkansas).
37) Regrade: to change the contour of any surface by the use of leveling or grading equipment (West Virginia).
38) Ridge: a lengthened elevation of overburden created in the strip mining process (Oklahoma).
39) Roads, Access or Haulageway: any road constructed or improved by the operator which ends at a pit or bend. Paths or trails between pits or benches for the temporary movement of equipment shall not be considered as haulageways but, nevertheless, shall be considered part of the disturbed area (Maryland).

40) Seepage Water: any water entering the ground from the surface through capillary action, cracks, faults or any other natural modes of entry and finding its way to the surface again (West Virginia).
41) Serrate: notched or narrow benches used on slopes to prevent erosion (Maryland).
42) Shaping: grading, backfilling and other earth moving to be done by the operator in connection with the reclamation of the area affected (Tennessee).
43) Shipping Areas: those areas used by the operator, or his agent, as temporary stockpiling areas for shipment of coal (Maryland).
44) Solid Bench: the portion of the bench between the highwall and the fill bench and thereby within the region once occupied by the mineral or overburden (Tennessee).
45) Spoil Banks: overburden removed from its natural position and deposited elsewhere in the process of surface mining (Iowa).
46) Steep Slope: any slope above twenty degrees or such lesser slope as may be defined by the regulatory authority after consideration of soil, climate and other characteristics of a region or state (House Resolution 25).
47) Stock Pile: material, including but not limited to, surface overburden, rock or lean ore, which in the process of mining and beneficiation or treatment has been removed from the earth and stored on the surface thereof, but excluding therefrom materials which are in the course of being treated in the production of mineral products and the mineral product which has been produced by such operation (Michigan).
48) Strip Mining: the breaking of the surface soil in order to facilitate or accomplish the extraction or removal of minerals, ores, or other solid matter; any activity or process constituting all or part of a process for the extraction or removal of minerals, ores and other solid matter from its original location; and the preparation, washing, cleaning, or other treatment of minerals, ores, or other solid matter so as to make them suitable for commercial, industrial, or construction use; but shall not include those aspects of deep mining not having significant effect on the surface and shall not include excavation or grading when conducted solely in aid of on-site farming or construction (Kentucky).
49) Tailings Pond: an area on a strip mine enclosed by a man-made or natural dam onto which has been discharged the waste material resulting from the primary concentration of minerals in ore excavated from the strip mine (Idaho).
50) Terracing: grading so that the steepest highwall slope is not greater than thirty-five degrees, with bench slope established by the commissioner, and the remaining overburden graded to the approximate original contour of the land or such other grading of the remaining overburden as the commissioner may approve or require, without depressions to hold water, and with adequate provision for drainage (Ohio).

51) Top-Soiling Material: the top soil, subsoil and other material that will support vegetation, occurring on and beneath the original pre-mining surface (Maryland).

4.2.0 Federal Laws

At the present time there are no federal laws to regulate strip mining. However, the 94th Congress of the U.S. has passed a resolution, H.R. 25, for controlling surface mining and for reclamation of the disturbed land. It is called the "Surface Mining Control and Reclamation Act of 1975." The resolution has been vetoed by President Ford and the veto was upheld in Congress in June 1975. However, H.R. 25 is the major piece of federal legislation and it seems appropriate to consider its highlights here.

The discussion that follows pertains only to the subject of erosion control processes related with reclamation. Four topics will be discussed: 1) the advisory board and the duties pertaining to reclamation, 2) application requirements, 3) reclamation standards for surface mines, 4) abandoned mine reclamation.

4.2.1 Advisory Board

H.R. 25 proposes the creation of the Department of the Office of Surface Mining Reclamation and Enforcement, within the Interior. This Office would have several major functions for coal mine reclamation, among which are:

1) review and approve or disapprove State programs for controlling surface coal mining operations;
2) order the suspension, revocation, or withhold any permit for failure to comply with the Act;
3) publish and promulgate rules and regulations necessary to carry out the purposes of the Act;
4) administer the program for the purchase and reclamation of abandoned and unreclaimed mined areas;

5) maintain a continuing study of surface mining and reclamation operations in the United States;
6) develop and maintain an information and data center on surface coal mining, reclamation and surface impacts of underground mining in which the data will be available to the public and to federal, regional, state and local agencies;
7) assist the States in developing scientific criteria, procedures and institutions for determining those areas of the state to be designated unsuitable for surface coal mining.

The primary regulatory and enforcement responsibilities would rest with the States and not with the Federal government, with minimum Federal standards applying to all States. If a State chose not to or failed to submit an adequate state program for Federal approval, the Federal government would implement State programs on State and private lands.

4.2.2. Application Requirements

The following application requirements have to be met for acceptance. The requirements stated below are a partial list for the application and deal only with reclamation and erosion control aspects.

An accurate map or plan must accompany the application showing all the land that is to be affected by the surface mining operation. All types of information are to be inscribed on topographical maps from the United States Geological Survey of a scale of 1:24,000 or larger including all man-made features and significant known archeological sites existing at the date of application. The map must show all boundaries and names of present owners of all surface areas abutting the permit area and the location of all buildings within one thousand feet of the permit area [3].

The names of the watershed or watersheds must be included in the application and on the topographical map. Also, all surface streams or tributaries into which surface and pit drainage will be discharged must be included.

The operator must do a preliminary determination of the hydrologic consequences of the surface mining and reclamation operations, both on and off the mine site. The hydrologic investigation must include analysis of the quantity and quality of water in surface and groundwater systems including the dissolved and suspended solids and sediment under seasonal flow conditions. Sufficient data must be collected of all anticipated mining in the area so that an assessment can be made of the impacts upon the hydrology of the area and particularly upon water availability.

The application should also include cross-sectional maps or plans of the land to be affected. These are to be prepared and certified by a registered professional engineer, or a registered land surveyor and a professional geologist. These maps are to show:

1) pertinent elevation and location of test borings or core samples;
2) the nature and depth of the various strata of overburden;
3) the location and quality of subsurface water;
4) the nature and thickness of any coal or rider seam above the coal seam to be mined;
5) the nature of the stratum immediately beneath the coal seam to be mined;
6) all mineral crop lines and the strike and dip of the coal to be mined within the area of the land to be affected;
7) existing or previous surface mining limits;
8) the location and extent of known workings or any underground mines, including the openings of the mines;
9) the location of the aquifers;
10) the estimated elevation of the water table;
11) the location of the spoil, waste, or refuse areas and topsoil preservation areas;

12) the location of all impoundments for waste or erosion control;
13) any settling or water treatment facilites;
14) the location of constructed or natural drainways and the location of any watersheds that drain to any surface body of water on the affected land or land adjacent to it; and
15) profiles of the anticipated final surface configuration for the proposed reclamation plan (A typical example is shown in Figure 4.1).

Each application must include a reclamation plan. The reclamation plan must include the following major points:

1) The operator must identify the entire area to be mined and the area that is to be affected by the mine over the estimated life of the project. The size, sequence and timing of the subareas in which individual mining permits will be sought must be stated.
2) A detailed description of how the proposed post-mining land use is to be achieved is required.
3) The engineering techniques proposed in mining and reclamation is required for the application. This must include a) a plan for the control of surface water drainage and of water accumulation, b) a plan for backfilling (see Figure 4.1), for soil stabilization, and for compacting, grading and revegetation, and c) an estimate of the cost per acre of the reclamation.
4) The applicant must give a detailed description of the measures to be taken during the mining and reclamation process to assure the protection of the quantity and quality of surface and groundwater systems, both on and off the site.

4.2.3. Reclamation Standards for Surface Mining

Listed below are the proposed minimum federal standards for reclamation in the United States. The reclamation standards with respect to erosion control, revegetation and siltation structures are discussed.

H.R. 25 does not specify how to control erosion. It does specify that erosion may not occur in any area of the mining operation, especially in the following areas: overburden or spoil piles, offsite areas and access roads. The overburden or spoil pile should be shaped and graded in such a way as to prevent slides and erosion. Roads and access ways should not come up a stream bed or drainage channel or in

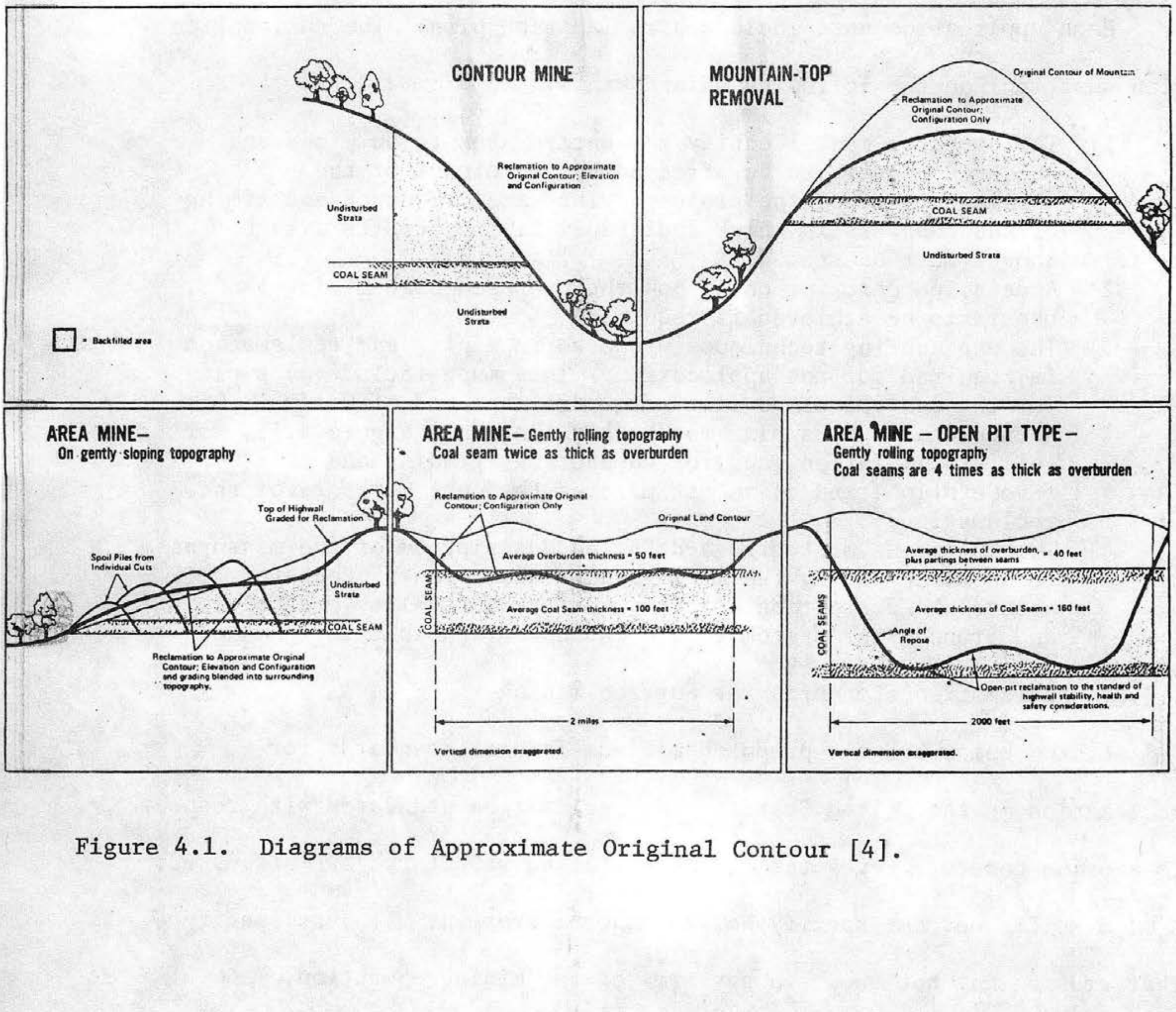

Figure 4.1. Diagrams of Approximate Original Contour [4].

the proximity of the channel so as to seriously alter the normal flow of water.

The surface mining operations should be conducted so that additional contributions of suspended solids to the streamflow is prevented to the maximum extent possible. Measurements for suspended sediment should be conducted under seasonal flow conditions both before and during the mining operation.

Both during and after the mining operation the operator should construct and maintain the access roads into and across the operation site in such a way as to control and prevent erosion and siltation. This is provided that the regulatory authority permits access roads to be left after the mining operation and reclamation is completed. The toe of the lowest coal seam mined and the overburden associated with it are to be retained in place as a barrier for slides and erosion. For erosion control purposes the resulting rolling contour drains inward from the outslopes except at specified points.

Revegetation of the affected land is needed for erosion control, agricultural purposes, grazeland, and housing and industrial sites. First and foremost, though, is the containment of the erosional processes. After this has been achieved or coinciding with erosion control schedule, the other factors for revegetation can be started. H.R. 25 states that the land affected must be restored to a condition that is at least as capable as the land was prior to any mining. On the land that is affected, a diverse, effective and permanent vegetative cover native to the area of land to be affected should be used. The vegetative cover should be capable of self-regeneration and plant succession at least equal to the natural vegetative cover of the area. An exception to this policy is that introduced species may be used where desirable and necessary to achieve the approved post-mining land use plan.

Higher or better uses of the affected land can be established so long as it does not present any actual or probable hazards to public health or safety or pose any actual or probable threat of water diminution or pollution. This is of course that the proposed land use following reclamation is not impractical or unreasonable, or inconsistent with applicable land use policies and plans.

The operator assumes the responsibility for successful revegetation for a period of five full years after the last year of augmented seeding, fertilizing and irrigation. In areas of the country where the annual average precipitation is twenty-six inches or less, the operator assumes the responsibility for successful revegetation for a period of ten full years after the last year of augmented seeding, fertilizing and irrigation.

For successful revegetation programs the top-soiling material must be removed and separated from the rest of the overburden and replaced as the top-soiling material at the completion of the project in the specified areas. If the top-soiling material is not utilized immediately the soil must maintain a successful cover by quick growing plants or by other means so that the topsoil is preserved from wind and water erosion, soil deterioration and acid or toxic material contamination. If other strata are found to be more suitable for top-soiling material the operator shall remove, segregate and preserve in a like manner as regular top-soiling material.

Siltation structures can and should be built where there is a large amount of sediment entering the streams below the affected land. The impoundment dam shall be designed and constructed so as to achieve the necessary stability, with an adequate margin of safety.

After the disturbed areas are revegetated and stabilized the temporary or large siltation structures can be removed.

4.2.4. Abandoned Mines Reclamation

Abandoned mine lands are a problem found in every region of the United States. Contour strip mining has created thousands of mines of unstable outslopes below the mined bench which were abandoned by the coal operator after the coal was exhausted. It is estimated that a million and a half acres of land have been directly disturbed by all coal mining and over 11,500 miles of streams have been polluted by sedimentation or acidity from surface or underground mines. Program costs for correcting these problems are estimated at nearly $10 billion as summarized below [4].

		Millions
1.	Stabilization, reshaping and revegetation of strip mined lands	$2,040
2.	Controlling acid mine drainage, clearing heavily silted streams, sealing of mineshafts	6,600
3.	Stabilization of mine waste banks and removal of fire and flood hazards	220
4.	Control of subsidence under urbanized areas	1,000
5.	Extinguishment of underground and outcrop mine fires	50
	Total	$9,910

H.R. 25 establishes funds to be used in the reclamation of abandoned lands. The obligations of the funds are listed below according to their priority [3]:

a) reclamation of previously mined areas;
b) the protection of health or safety of the public;

c) protection of the environment from continued degradation and the conservation of land and water resources;
d) the protection, construction, or enhancement of public facilities such as utilities, roads, recreation and conservation facilities and their use;
e) the improvement of lands and water to a suitable condition useful in the economic and social development of the area affected; and
f) research and demonstration projects relating to the development of surface mining reclamation and water quality control program methods and techniques in all areas of the United States.

4.3.0. State Laws

At the present time, thirty-two States have some form of strip mining reclamation regulations. Some of the requirements in the laws are duplicates of other State laws with almost all of the laws being similar in one aspect or another.

The following four topics will be discussed: 1) the governing and advisory boards; 2) application requirements; 3) reclamation and, 4) abandoned mines.

4.3.1. Governing and Advisory Boards

Most states have a governing board for controlling permit applications. A few States have advisory boards which are used to bridge the gap between the governing board and the operators. Aspects of both types of boards are listed below.

The governing board has control over all strip mining in the State. Each governing board has certain duties and requirements for the operators. Among these are [19,23]:

1) to enforce the state's reclamation laws;
2) conduct hearings and establish orders requiring the operator to adopt the remedial measures necessary to comply with the State's laws and regulations;
3) designate land that is unsuitable for strip mining.

To correspond to the governing board an advisory board is established for the following reasons [14,27]:

1) hear appeals from mineral owners, or other interested parties aggrieved by orders, determinations, regulations, or rulings of the governing board or commissioner which in any way affect surface mining in the State;
2) represent the unified interest of government, industry, and private individuals;
3) receive all complaints related to strip mining and strip mining operations;
4) review the strip mine law from time to time and to recommend such changes in the law as may be deemed advisable.

4.3.2. Application Requirements

The States that have major strip mining operations usually adopt application requirements that are similar in nature. The application requirements for the state of Montana as outlined in "The Montana Strip Mining and Reclamation Act" Title 50, Chapter 10 from the Revised Code of Montana effective March 16, 1973, is detailed below:

1) An operator may not engage in strip mining without having first obtained from the Department a permit designating the area of land affected by the operation. The permit shall authorize the operator to engage in strip mining upon the area of land described in his application and designated in the permit for a period of one year from the day of its issuance. Such permit shall be renewable from year to year.

2) An operator desiring a permit shall file an application which shall contain a complete and detailed plan for the mining, reclamation, revegetation and rehabilitation of the land and water to be affected by the operation. Such plan shall reflect thorough advance investigation and study by the operator and shall include all known or readily discoverable past and present uses of the land and water to be affected.

3) The application for a permit shall be accompanied by two copies of all maps meeting the requirements of the subsections below. The map shall:
    a) identify the area to correspond with the application;
    b) show any adjacent deep mining and the boundaries of surface properties and names of owners of record of the affected area and within one thousand feet of any part of the affected area;

c) show the names and locations of all streams, creeks, or other bodies of water, roads, buildings, cemeteries, oil and gas wells, and utility lines on the area of land affected and within one thousand feet of such area;
d) show by appropriate markings the boundaries of the area of land affected, any cropline of the seam or deposit of mineral to be mined and the total number of acres involved in the area of land affected;
e) show the date on which the map was prepared and the north point;
f) show the drainage plan on and away from the area of land affected. This plan shall indicate the directional flow of water, constructed drainways, natural waterways used for drainage, and the streams or tributaries receiving the discharge;
g) show the proposed location of waste or refuse area;
h) show the proposed location of temporary subsoil and topsoil storage area;
i) show the location of test boring holes;
j) show the surface location lines of any geologic cross-sections which have been submitted;
k) show a listing of plant varieties encountered in the area to be affected and their relative dominance in the area, together with an enumeration of tree varieties and the approximate number of each variety occurring per acre on the area to be affected and the locations generally of the various kinds and varieties of plants, including but not limited to grasses, shrubs, legumes, forbs and trees;
l) contain such other or further information as the governing board may require;

4) In addition to the information and maps required above, each application for a permit shall be accompanied by detailed plans or proposals showing the method of operation, the manner, time or distance and estimated cost for backfilling, grading work, highwall reduction, topsoiling, planting, revegetating and a reclamation plan for the area affect by the operation, which proposals shall meet the requirements of the law.

4.3.3. Reclamation

Reclamation requirements vary widely among the various States. The States have set their reclamation requirements according to the amount of strip mining occurring in the State, hydrologic conditions, precipitation, soil conditions, soil type and cover vegetation. Thus, each State has different requirements for the protection of the environment. The States that belong to the Interstate Mining Compact have some of the most complete regulations concerning this aspect of the problem.

The reclamation section is divided into four subsections. These are: erosion control, drainage, silt dams and revegetation.

Erosion Control: Erosion control is divided in: Backfilling spoil banks and haulageways. Backfilling requirements are divided into two categories: one for contour strip mining and another for area strip mining. Contour strip mining is used in hilly or mountainous terrain where the slope of the land is usually greater than 12 degrees. Area strip mining is on slopes that are less than 12 degrees. A typical method of contour mining and reclamation is shown in Figure 4.2. The operator will follow the coal seam around the hill or mountain until the depth of overburden because too large to make the operation feasible.

Backfilling and grading usually follows a 1000 to 1500 feet behind the stripping operation or 60 days after the completion of the operation [16,32]. Two types of backfilling are used in contour strip mining. These are: approximate original contour method and terracing. In general any area where the slope of the original land was less than 12 degrees from the horizontal should be restored with the approximate original contour method. This is shown in Figure 4.3a. The material removed or disturbed prior to the extraction of the coal must be put back or replaced after the extraction. With this method the final surface of the restored area will not necessarily have the same exact elevations as the original ground surface due to the fact that the overburden will swell when exposed to air and the lack of compaction of the loose material. However, the final restored area should have the same general relative contour as it had originally [16].

Terracing is the usual method of backfilling when the angle of inclination is 12 degrees or more from the horizontal. Figures 4.36 and 4.4 show typical methods of terracing. The final slope of the highwall and the outerslope of the spoil bank should not be greater than 35 degrees from the horizontal (see Figure 4.4 (a) and (b). Unserrated slopes of 35 degrees should not exceed 25 feet in slope distance as measured downslope. The table portion of the restored area should be a terrace of a slope not greater than five degees (see Figure 4.3). There should be a minimum of four feet of cover over the pit floor. There should be no depressions to hold water and no lateral depressions or drainage ditches of sufficient length to cause erosion in the restored area. The maximum slope for a fill bench should not exceed 20 degrees [16].

With multiple cut or area mining operations the material produced from the first cut is moved out of the way of the mining operation (see Figure 4.5 (a) and (b).) The overburden from the second cut is placed into the pit created by the first cut and so on (see Figure 4.5 and 4.6). The spoil pile from the first cut may be a considerable distance from the pit made by the last cut which must be leveled. Excess spoil from the other cuts is pushed in a general direction of the last cut to fill that cut in. Approximate original contour should be obtained in this method.

Contour strip mining uses the same basic extraction method as area mining. This is called the modified block-cut method. This is shown in Figure 4.5. The only difference between the contour and area strip mining is that an outcrop barrier is made to protect from slide damage.

Spoil banks should be sloped so as to minimize erosion. The Code of Iowa 1975 [14] states that a maximum slope for the spoil banks to be one foot of vertical rise for each four feet of horizontal distance except when the original topography was steeper, then the spoil bank is to be graded to blend with the surrounding terrain. The maximum permitted slope varies from State to State with Iowa's specification being about average.

Abandoned haulageways should be protected from erosion. Culverts and any other erosion control devices may be used.

Drainage: Drainage is a problem for both erosion and toxic soil contamination. Natural drainways should be kept free of overburden. Usually strip mining operations are prohibited near a drainway, but in some cases, when approved, overburden can be placed in the drainway. Overburden that is placed over natural drainways must be constructed so as not to affect the flow of the stream, or materially increase the sediment load in the stream.

Constructed drainways can be built above the highwall, on the bench, and below the spoil slope. Which of these are needed depends upon the site location. Highwall drainways are used to intercept the surface water on the uphill side of the highwall. The water is conveyed around the strip mining site.

Bench drainage ditches are constructed on the solid bench to carry off storm, surface, or seepage water. The removal of the

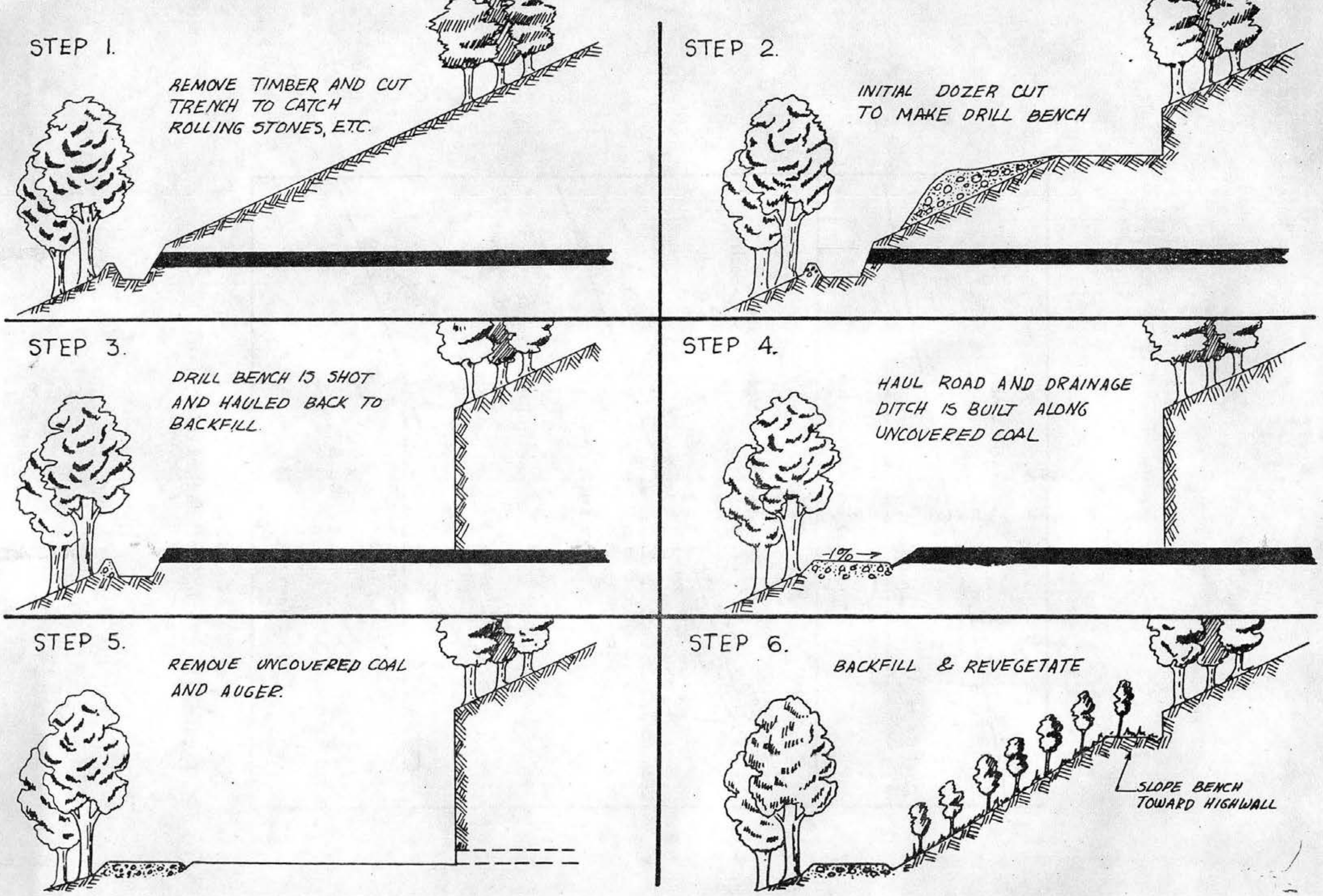

Figure 4.2. Typical Method of Contour Mining and Reclamation [33].

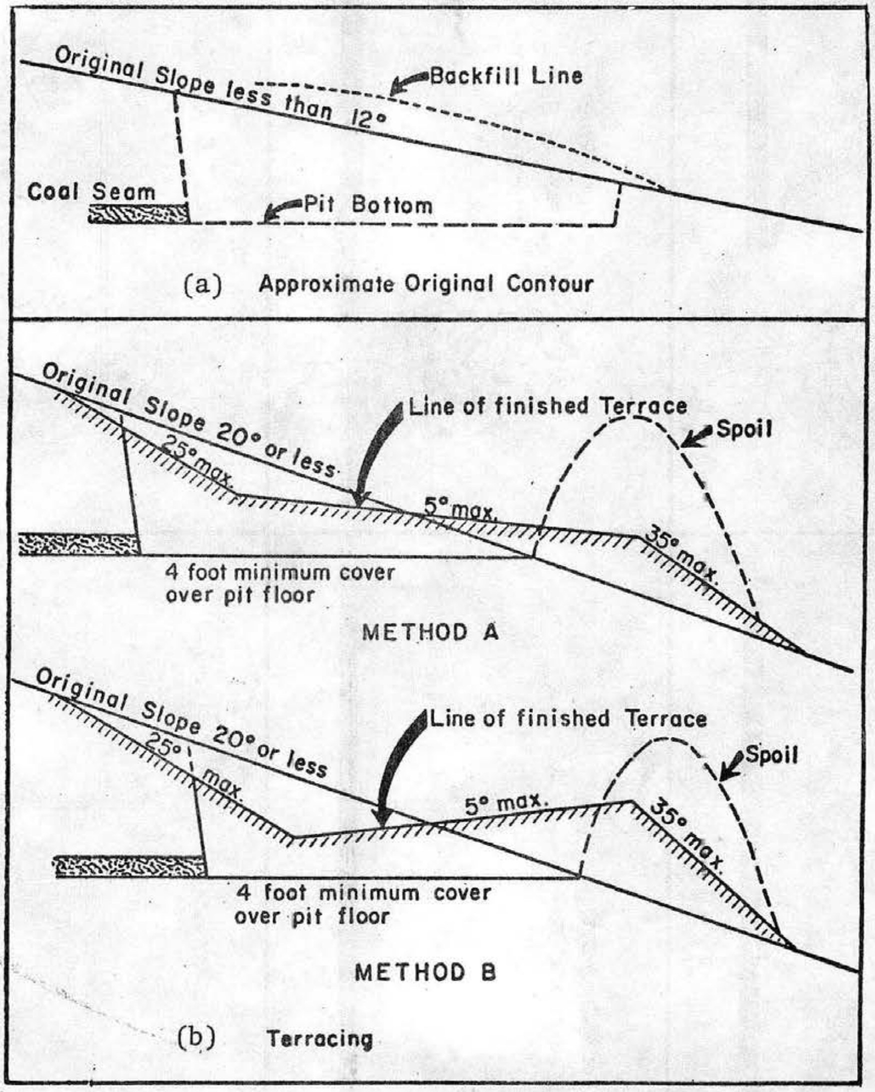

Figure 4.3 Method of Backfilling [16].

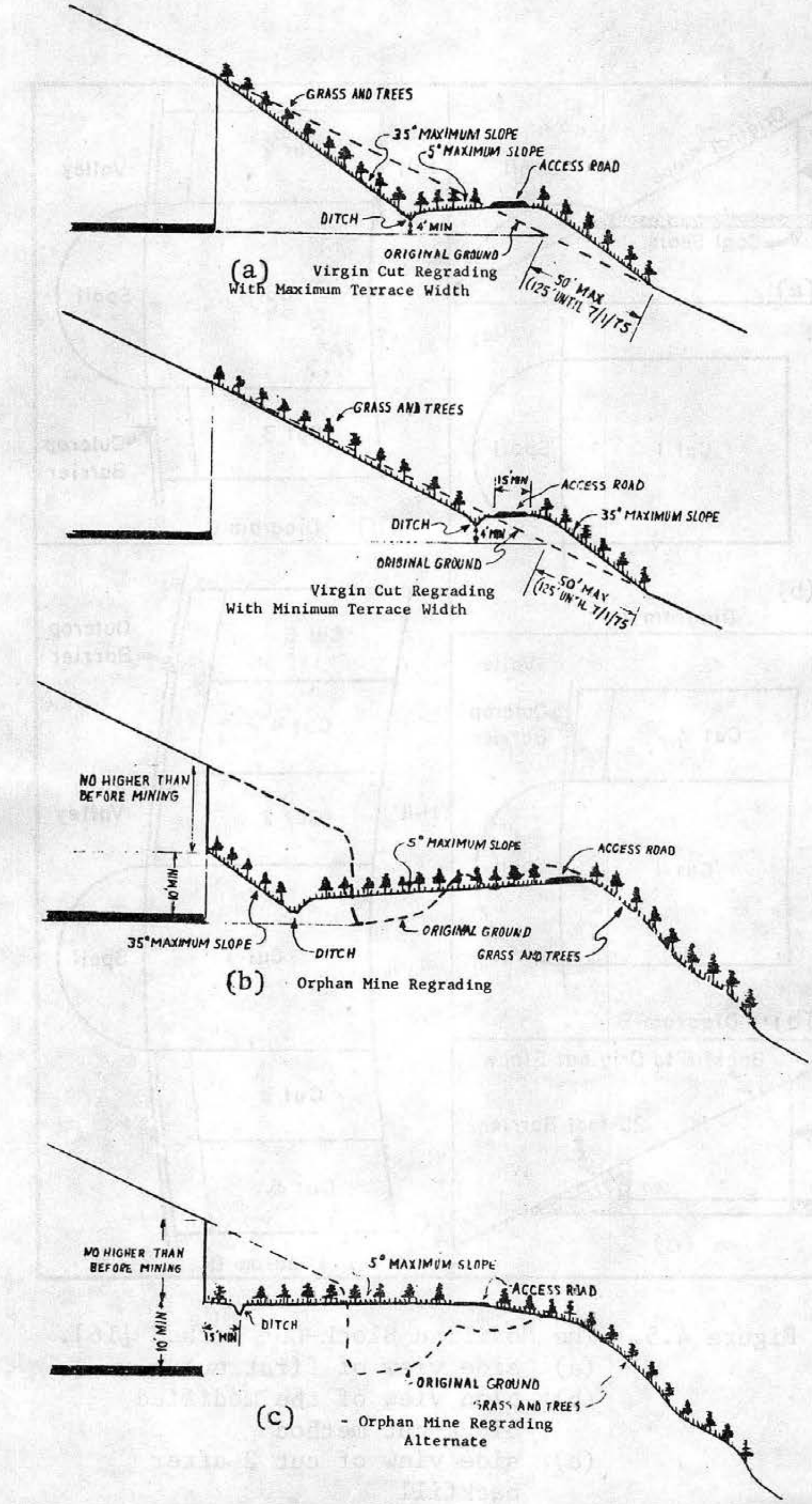

Figure 4.4. Final Grading for Virgin Cut Regrading and Orphan Mine Regrading [28].

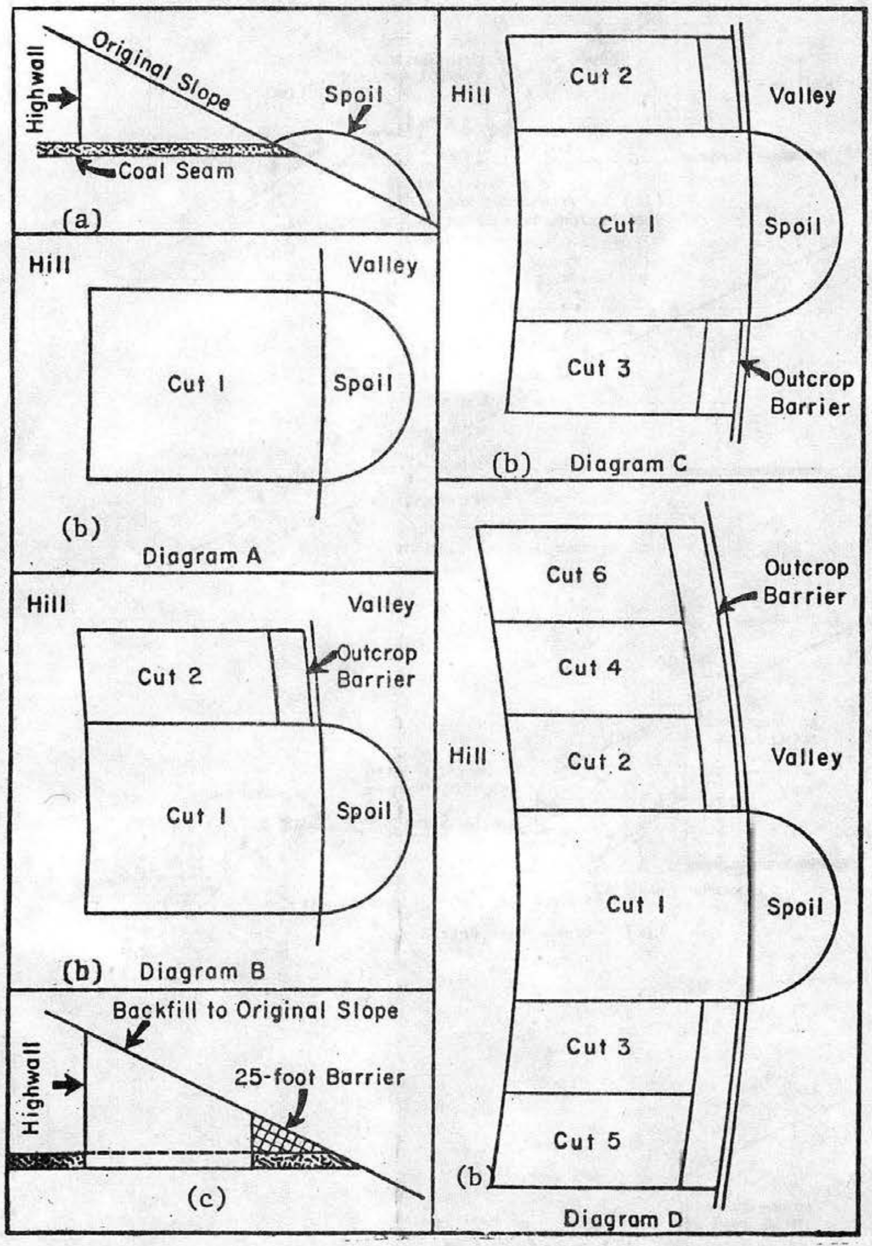

Figure 4.5. The Modified Block-Cut Method [16].
(a) side view of first cut
(b) plan view of the modified block-cut method
(c) side view of cut 2 after backfill

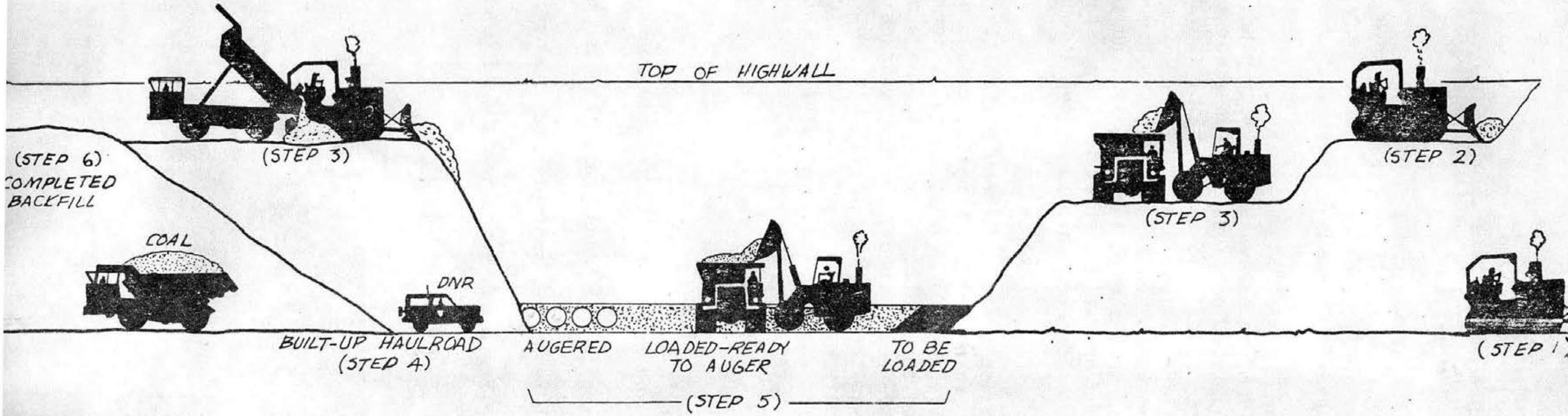

Figure 4.6. Controlled Placement of Spoil in Surface Mining, [33].

water from the bench should be accomplished by the use of pipe, rock riprap flume, asphalt or concrete chutes, or by grading a channel in a nonerosive rock [32].

Below the spoil slope drainage ditch collects all water that drains off the spoil slope. These ditches should be located near the anticipated tow of the spoil slope. This water must be carried to suitable treatment ponds before discharge into a natural drainway.

Silt Dams: Embankment dams or excavated sediment ponds should be constructed in appropriate locations if needed for controlling sediment for the affected area. The West Virginia Surface Mining Reclamation Regulations of 1971 stipulates that 0.125 acre-ft/acre of disturbed area in the watershed is needed for minimum reservoir capacity. The disturbed area should include all land that has been affected by previous operations which have not stabilized and all land that will be affected throughout the life of the operation.

Revegetation: After the operation has been backfilled, graded and approved by the governing board the operator should prepare the soil for a vegetative cover. Usually, a quick permanent protective cover is used to stabilize the soil from erosion. Once the soil has a protective cover trees, shrubs, grasses and legumes can be planted so long as they provide a suitable protective cover and are satisfactory with the governing board. Lime, fertilizer and irrigation can be used to help provide for a suitable cover. Each State has their own standards for the type of cover and the quantity involved.

4.3.4. Abandoned Mines

Presently, very few if any States try to reclaim abandoned lands. Most States will reclaim any affected lands where the bond has been forfeited and used financial resources appropriated from strip mining and reclamation funds if the State has set aside a fund. An example of orphan mine regrading is included in Fig. 4.4.

4.3.5 Summary

Thirty-two States have strip mine reclamation legislation. Each of these State laws are different from one another depending upon many factors, such as: the extent of strip mining in the State, hydrologic and watershed characteristics, precipitation and soil types and erosion capability.

There are very few actual methods of erosion control that are stated in State laws. Each application for a permit must be reviewed separately because of the many local factors affecting the reclamation for that area. Thus, the governing board in each State establishes the particular reclamation requirements of each site. Table 4.5 lists the various pieces of current state legislation and a summary of the reclamation requirements included in each of them.

TABLE 4.5
SUMMARY OF RECLAMATION REQUIREMENTS OF STATE LAWS [34]

STATE	RECLAMATION REQUIREMENTS
ALABAMA	Reduce peaks and ridges to a width of 15 feet at the top; cover face of toxic material; divert water to reduce siltation, erosion or damage to streams and natural water courses; plant trees or direct-seed the affected land; revegetate haulage roads and land used to dispose of refuse; and construct fire lanes or access roads in acres to be reforested. Reclamation to be completed within 3 yrs. of expiration of permit period.
ARKANSAS	Grade peaks and ridges to a rolling topography; construct earth dams; in areas to be reforested, construct fire lanes or access roads at least 10 feet wide; strike peaks and ridges to a minimum of 20 feet at the top on all land to be seeded for pasture; cover exposed acid forming material; and dispose of refuse so as to control erosion or damage to streams or natural water courses. Reclamation to be completed prior to the expiration of 2 yrs. after termination of permit.
COLORADO	Grade ridges and peaks to a width of 15 ft. at the top; where practical, construct earth dams in final cuts to impound water; cover acid forming material to protect drainage system from pollution; and dispose of all refuse so as to control stream pollution, and divert water to control siltation, erosion, or other damage to streams and natural water courses. The Act further contains specific requirements for reclaiming disturbed areas for various uses including forest, range, agricultural or horticultural crops, homesites, recreational and industrial.
FLORIDA	The Act imposes a severance tax on the extraction of certain solid minerals. A mine operator may obtain a refund of up to 60 percent of the tax imposed by the Act for developing and instituting a reclamation and restoration program.

STATE	RECLAMATION REQUIREMENTS
GEORGIA	Grade and backfill peaks, ridges, and valleys to a rolling topography; cover exposed toxic ores or mineral solids with a minimum of 2 feet of soil capable of supporting a permanent plant cover; and establish permanent ground cover on affected lands the first growing season following grading.
IDAHO	Level ridges of overburden to a minimum of 10 feet at the top; level peaks of overburden to a minimum of 15 feet at the top; prepare overburden piles to control erosion; minimize siltation of lakes and streams as a result of water runoff from affected lands; crossditch abandoned roads to avoid erosion gullies; plug exploration drill holes; when possible, top affected land with overburden conducive to erosion control and establishment of vegetative growth; prepare tailings ponds so as not to constitute a hazard to human or animal life; and complete reclamation within 1 year after surface mining operations permanently cease or are abandoned.
KENTUCKY	Complete backfilling not to exceed the original contour with no depressions to accumulate water is required of all land affected by area mining. All highwalls resulting from contour strip mining shall be reduced or backfilled, the steepest slope of the reduced or backfilled highwall and the outer slope of the fill bench being no greater than 45 degrees from the horizontal. The table portion to be terraced with a slope not greater than 10 degrees. The restored area to have a minimum depth of 4 feet of fill over the pit floor. Revegetation shall include planting trees, shrubs, grasses legumes. Reclamation to begin as soon as possible after strip mining begins and completed within 12 months after the permit has expired.
MAINE	Varied-depending on planned future use of reclaimed land. The intent of the Commission is to insure that an approved permanent vegetative cover is established where possible on affected land, and that the conditions in which the land is left is not conducive to erosion or pollution.

MARYLAND	Grade spoil banks to reduce depressions between peaks of spoil to a surface which restores the terrain to a condition prescribed by the Director, Bureau of Mines; if overburden deposits are composed of materials which are suitable for supporting vegetative growth, it shall be graded so as to cover the final pit; and seal-off, with a fill, underground mining operations at the base of the final cut.
MICHIGAN	The Act authorizes the Chief of Geological Survey to conduct a comprehensive study and survey to determine the type of regulation needed to protect the public interest. Upon completion of the survey rules may be promulgated governing: Sloping, terracing or treatment of stockpiles and tailings to prevent damage to fish and wildlife, pollution of waters or injury to persons or property; vegetation or treatment of tailings basins and stockpiles where natural vegetation is not expected within 5 years and where research reveals vegetation can be accomplished within practical limitations; and stabilization of the surface overburden banks of open pits in rocks and the entire bank of open pits in unconsolidated material.
ILLINOIS	Grade affected land to a rolling topography with slopes having no more than a 15% grade, except land reclaimed for forest plantation, recreational or wildlife, the final cut spoil, the box-cut spoil, and the outside slopes of all overburden deposition areas, the grade shall not exceed 30%; return land to be used for row crop to approximate original grade and, when availalbe, segregate and replace at least 18 inches of topsoil; impound runoff water to reduce soil erosion, damage to unmined lands, and pollution of streams and waters; cover exposed acid forming material with not less than 4-6 feet of water or other materials capable of supporting plant and animal life; confine slurry in depressed or mined areas; remove and grade all haulage roads and drainage ditches; and plant trees, shrubs, grasses and legumes. All reclamation except slurry and gob areas in active use shall be completed prior to the expiration of 3 years after termination of permit year.

INDIANA	Grading to reduce peaks and ridges to a rolling, sloping or terraced topography; construct earth dams in final cuts to impound water; bury all metal, lumber, or other debris or refuse resulting from mining; and revegetate affected areas as soon as practicable after initiation of mining operations.
IOWA	Grade spoil banks to slopes having a maximum of 1-foot vertical rise for each 3-feet horizontal distance, except where the original topography exceeds these stipulations, and spoil bank shall be graded to blend with surrounding terrain; construct an earth dam where a lake or pond may be formed to properly control the drainage of acid water from the site; and cover acid forming material with at least 2 feet of earth or spoil material. Operators shall rehabilitate affected areas within 24 months after mining is completed.
KANSAS	Grade each pit to a flat surface with a width equal to at least 60% of the original pit; cover the face of coal or other minerals with non-acid bearing and non-toxic materials to a distance of at least 2 feet above the seam being mined, or by a permanent water impoundment; control flow of all runoff water to reduce soil erosion, damage to agricultural lands, and pollution of streams and waters; and grade overburden to provide suitable vegetative cover. Reclamation must be pursued as soon as possible after mining begins and completed within 12 months after the permit has expired.
MISSOURI	Grade peaks and ridges of overburden, except where lakes are to be formed, to a rolling topography traversable by farm machinery. The slopes need not be reduced to less than the original grade prior to mining, and the slope of overburden ridge resulting from a box cut need not be reduced to less than 25 degrees from the horizontal. Dispose of all debris, material or substance removed from the surface prior to mining.

MONTANA	Bury under adequate fill all toxic materials; seal off breakthrough of water creating a hazard; impound,drain or treat runoff water so as to reduce soil erosion, damage to grazing and agricultural lands, and pollution of surface and subsurface waters; and remove and bury all refuse resulting from the operation. Segregate, preserve, and replace topsoil. All highways must be reduced, the steepest slope of which shall be no greater than 20 degrees from the horizontal. Backfilled, graded and topsoiled areas shall be prepared and planted with legumes, grasses, shrubs, and trees. Reclamation to begin as soon as possible after beginning strip mining.
NEW MEXICO	Grade to produce a gently undulating topography or such other topography as is consistent with planned end use of the land. Grading shall be done in such a manner as to control erosion and siltation of the affected area and surrounding property and water courses. Revegetation of the affected area must be accomplished in accordance with the previously approved mining plan.
NEW YORK	Reclamation to be accomplished in accordance with the approved reclamation plan which shall indicate specific covering revegetation, disposal of debris, refuse, tailings, waste, and spoil grading. Reclamation to be completed within a 2-yr. period after mining ceases.
NORTH CAROLINA	Reclamation must be performed in accordance with approved reclamation plan which must meet the following standards: The final slopes in all excavations in soil, sand, gravel, and other unconsolidated materials shall be at such an angle as to minimize the possibility of slides and be consistent with the future use of the land. Provisions for safety to persons and to adjoining property must be provided in all excavations in rock. In open cast mining operations, all overburden and spoil shall be in a configuration which is in accordance with accepted conservation practices and which is suitable for the proposed subsequent use of the land. Suitable drainage ditches or conduits shall be constructed to prevent collection of small pools of water that are noxious, odiuous, or foul. The type of vegetative cover and method of its establishment shall conform to accepted agronomic and reforestation practices.

NORTH DAKOTA	Regrade affected area to approximate original contour, or rolling topography or topography for higher end use; spread topsoil or other suitable soil material over the regraded area to a depth of two feet; impound or treat run-off water to reduce soil erosion, damage to agricultural lands and pollution of streams; back-slope final cuts and end walls to an angle not to exceed 35 degrees from the horizontal- (operator may propose alternative to backfilling if consistent with the Act); remove or bury all debris; and sow,set-out, or plant cuttings or trees, shrubs, grasses, or legumes. All reclamation shall be carried to completion prior to the expiration of three years after termination of the permit terms.
OHIO	Cover all acid producing materials with non-toxic material; construct and maintain access roads; prevent the pollution of waters,erosion, landslides, flooding and the accumulation or discharge of acid water; contour the affected area unless the mining and reclamation plan provides for terracing or other uses; and replace segregated topsoil and grow vegetative covering.
OKLAHOMA	Grade peaks and ridges of overburden to a rolling topography, but the slopes need not be reduced to less than the original grade prior to mining, and the slope of ridge resulting from the box cut need not be reduced to less than 25 degrees from the horizontal; construct earth dams to form lakes in pits resulting from surface mining operations; cover exposed faces of mineral seams with not less than 3 feet of earth to support plant life or with a permanent water impoundment; and revegetate affected land, except that which is to be covered with water or used for homesites or industrial purposes, by planting trees, shrubs or other plantings appropriate to future use of the land.

STATE	RECLAMATION REQUIREMENTS
OREGON	Reclamation of the affected land must be performed in accordance with the approved reclamation plan which must contain; measures to be undertaken by the operator in protecting the natural resources of adjacent lands; measures for the rehabilitation of the surface-mined lands and the procedures to be applied; procedures to be applied to the surface mining operation to control the discharge of contaminants and the disposal of surface mining refuse; procedures to be applied in the rehabilitation of affected stream channels and stream banks to a condition minimizing erosion, sedimentation and other factors of pollution; such maps and other documents as may be requested by the Department of Geology and Mineral Industries; and a proposed time schedule for the completion of reclamation operations.
PENNSYLVANIA	Backfill all pits within 6 months after completion of mining. Such backfilling shall be terraced or sloped to an angle not to exceed the original contour. Plant grasses and trees or grasses and shrubs upon affected land within 1 year after backfilling.
SOUTH CAROLINA	Reclamation to be performed in accordance with the approved reclamation plan which must meet the following standards: The final slopes in all excavations shall be at such an angle so as to minimize the possibility of slides; provide safety of persons and of adjoining property; in open cut mining, overburden and spoil shall be left in a configuration suitable for subsequent use of the land; and construct suitable drainage to prevent the collection of small pools of water that are noxious or likely to become noxious, odious, or foul. The type of vegetative cover and method of its establishment shall conform to accepted recommended agronomic and reforestation practices. The plan must further provide that reclamation activities be completed within 2 years after completion or termination of mining on each segment of the area for which a permit is issued unless a longer period is specifically authorized.

STATE	RECLAMATION REQUIREMENTS
VIRGINIA	Remove all debris resulting from mining operations; regrade the area in a manner established by rules and regulations; grade overburden to reduce peaks and depressions between peaks to produce a gently rolling topography; preserve existent access roads; and plant trees, shrubs, grasses or other vegetation upon areas where revegetation is practicable.
SOUTH DAKOTA	Isolate all toxic or other material that have a damaging effect upon ground and surface waters, fish and wildlife, public health and the environment; reclaim surface mined areas to control erosion, provide vegetation, and eliminate safety hazards; replace topsoil evenly over reclaimed area; revegetate in accordance with agronomic and forestry recommendations; and upon completion of operations, remove all structures, machinery, equipment, tools & materials from the site of operation.
TENNESSEE	Goal: cover all acid producing material; seal off any breakthrough in mine or pit walls which creates a hazard; control drainage to prevent damage to adjacent lands, soil erosion and pollution of streams and waters; remove all refuse except vegetation resulting from the operation; provide adequate access roads to remote areas; on steep slopes, regrade area to approximate original contour or rolling topography & eliminate highwalls, spoil piles & water-collecting depressions, (Grading and other soil preparation to accommodate vegetation shall be completed within 6 months following initiation of soil disturbance.) Revegetate the affected areas with grasses or legumes to prevent soil erosion. Minerals other than coal: regrade the area to approximately the original or rolling topography, and eliminate all highwalls, spoil piles, and water collecting depres sions; control drainage to prevent soil erosion, damage to adjacent lands, and water collecting depressions, control drainage to prevent soil erosion, damage to adjacent lands, and pollution of streams and other waters; and revegetate with trees, grasses, or legumes.

STATE	RECLAMATION REQUIREMENTS
WASHINGTON	In reclaiming excavations for use as lakes, all banks shall be sloped to 2 ft below the groundwater line at a slope no steeper than 1 1/2 ft horizontal to 1 ft vertical. In all other excavations, the side slopes shall be no steeper than 1 1/2 ft horizontal to 1 ft vertical for their entire length. All strip pits and open pits shall be no steeper than 1 ft horizontal to 1 ft vertical. The slopes of quarry walls shall have no prescribed slopes, except where a hazardous condition is created the quarry shall be graded or backfilled to a slope of 1 ft horizontal to 1 ft vertical. In strip mining, peaks and depressions of spoil banks shall be constructed to a gently rolling topography. Suitable drainage shall be constructed to prevent the collection of stagnant water. All grading and backfilling shall be made with non-noxious, non-flammable, noncombustible solids. All acid-forming materials shall be covered with at least 2 ft of clean fill. Vegetative cover shall be required and all surface mining that disturbs streams must comply with State fisheries laws.
WEST VIRGINIA	Cover the face of coal & disturbed areas with material suitable to support vegetative cover; bury acid-forming materials, toxic material, or materials con= stituting fire hazard; impound water. Bury all debris. The law also contains requirements for regrading surface mined areas where benches result specifying the maximum bench width allowed. On land where benches do not result complete backfilling is required but shall not exceed the original contour of the land. The backfilling shall eliminate all highwalls and spoil peaks. Planting is required.

STATE	RECLAMATION REQUIREMENTS
WYOMING	Protect the removed and segregated topsoil from wind & water erosion & from acid or toxic materials; cover, bury, impound or otherwise contain radioactive material; conduct contouring operation to achieve planned use; backfill, grade, and replace topsoil or approved subsoil; replace vegetation; prevent pollution of surface & subsurface waters; and reclaim affected land as mining progresses in conformity with the approved reclamation plan.

Source: U.S. Bureau of Mines, Mining Environment, April 1975.

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9. Alabama State Code, Title 26, "The Alabama Surface Mining Act of 1969," (effective October 1, 1970).

10. Arkansas Statutes Annotated, Title 52, Chapter 9, "The Arkansas Open Cut Land Reclamation Act of 1971," (effective July 1, 1971), Act 236.

11. Idaho Code, Title 47, Chapter 15, "The Idaho Surface Mining Act," (effective May 31, 1971).

12. Illinois Annotated Statutes, Chapter 93-201, "The Illinois Surface-Mined Land Conservation and Reclamation Act-1971," Amended by House Bill 1277, Illinois 78th General Assembly, (effective July 1, 1975).

13. Indiana Coal Mining Laws, Chapter 168, Acts of 1955, Senate Enrolled Act No. 148, as amended by Acts of 1971, Senate Enrolled Act No. 547, (effective March 8, 1955).

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17. Michigan Statutes Annotated, Act No. 92 of the Public Acts of 1970, as amended by Act No. 123 of the Public Acts of 1972, Mine Reclamation Act, (effective March 29, 1973).

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25. Pennsylvania Statutes Annotated, Act of May 31, 1945 of Public Law 1198, as amended by Act No. 147, "Surface Mining Conservation and Reclamation Act," (November 30, 1971).

26. Pennsylvania Statutes Annotated, Act of May 31, 1945 of Public Law 1198, as amended by Act No. 147, Subchapter D., Requirements Accompanying Permits Authorizing the Operation of Surface Coal Mines, (effective September 11, 1972).

27. Tennessee Code Annotated, Chapter 15, "The Tennessee Surface Mining Law," (effective March 23, 1972).

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Chapter V

EROSION CONTROL TECHNOLOGOY IN STRIP MINING

5.1.0. Strip Mining Methods and Techniques

Strip mining methods can be divided into two general types: area and contour. Area strip mining is practiced on gently rolling to relatively flat terrain and is commonly found in the Midwest and Far West. In area strip mining, a trench or box cut is made through the overburden to expose the deposit of mineral or ore to be removed. The first cut may be extended to the limits of the property of the deposit. The overburden from the first cut is placed on unmined land adjacent to the cut, and the mineral is removed from the site by truck hauling. Once the first cut is completed, a second cut is made parallel to the first and the overburden from the succeeding cuts is deposited in the cut just previously excavated. The deposited overburden is called spoil. The final cut leaves an open trench equal in depth to the thickness of the overburden and the mineral bed removed, bounded on one side by the last spoil pile, and on the other by the undisturbed highwall. The final cut may be up to a mile or more from the starting point and the overburden from the cuts, unless graded or leveled, resembles a plowed field or the ridges of a gigantic washboard.

Contour strip mining is most commonly practiced where deposits occur in rolling or mountainous country. Basically, this method consists of removing the overburden above the bed by starting at the outcrop and proceeding along the hillside. After the deposit is exposed and removed by this first cut, additional cuts are made until the ratio of overburden to product brings the operation to a halt. This type of mining creates a shelf, or "bench," on the hillside. On the inside it is bordered by the highwall, which may range from a few to perhaps more than 100 feet in height and on the opposite, or outer, side by a rim below which there is frequently a precipitous downslope that has been covered by spoil material cast down the hillside.

5.1.1. Area Mining Methods

In the United States, area stripping is characterized by giant earth moving equipment capable of handling several thousand cubic yards of material per hour. With projects of this scale the need for increased sophistication of engineering, planning, management and administration of modern mining installations has become increasingly more apparent.

Simple overcasting, as shown in Figure 5.1, is the most common form of stripping. However, the long-range plans for effective land use before, during and after mining, the mining and reclamation methods to practice and the selection of stripping and reclamation equipment, must be considered in the context of social, technical and economic constraints. Pit engineering to avoid unnecessary inventory and quenching delays becomes important as all accessory equipment must be carefully matched to the primary equipment. Primary equipment selection is also difficult because of the availability of a wide range of equipment capable of working in all types of conditions.

In area stripping, shovels and draglines continue to be more popular, with draglines increasingly favored over shovels. They are available in a wide range of designs and capacities. Draglines provide greater flexibility, work on higher bank heights and move more cover per hour.

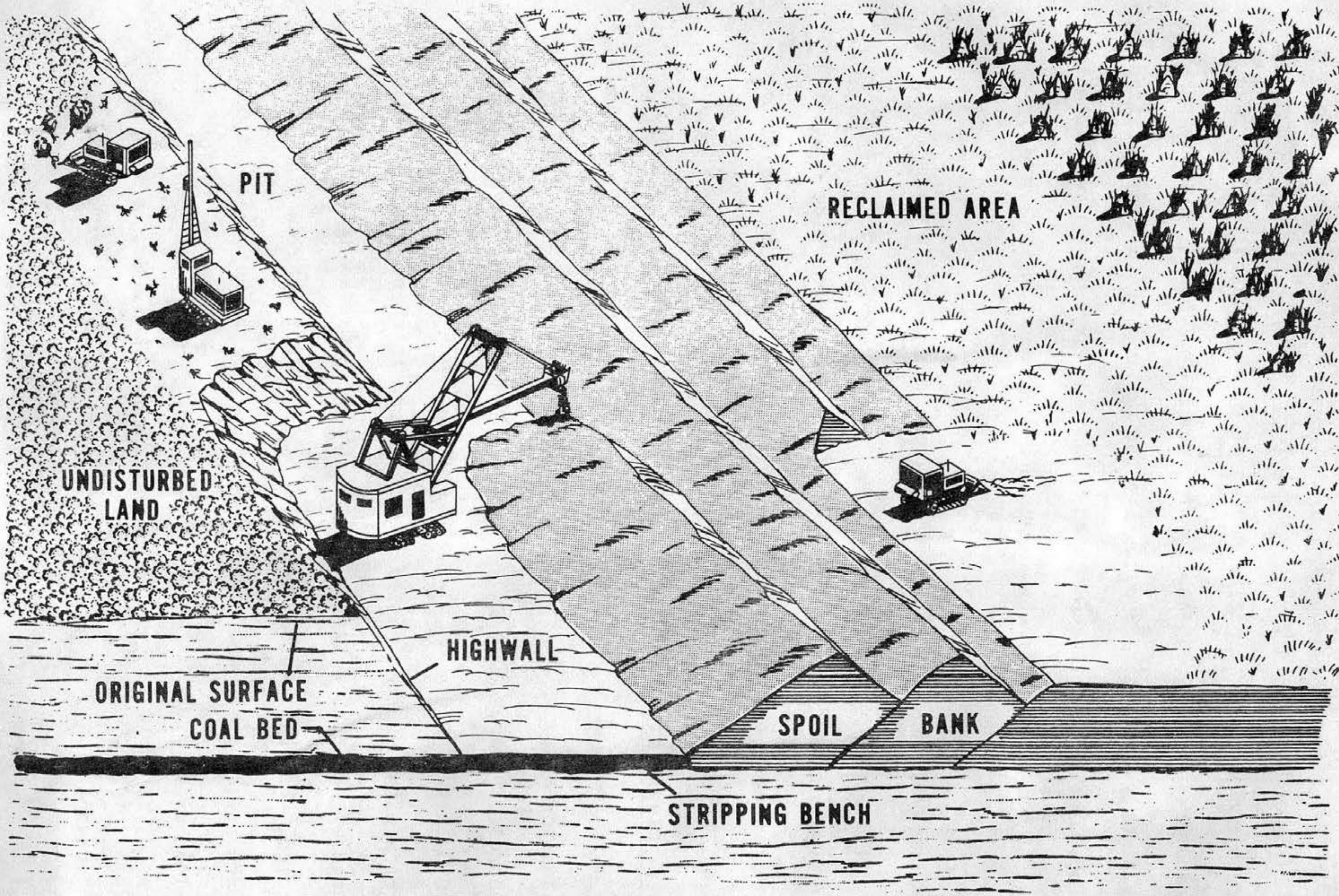


Figure 5.1. Area strip mining with concurrent reclamation.

Wheel excavators hold considerable promise where conditions are favorable. Ideally, this machine has the capability for continous overburden removal and selective placement of the top soil. Designed capacities are up to 15,000 cubic yards per hour, though in practice figures of only 3,000 to 4,000 cubic yards per hour have been realized [1]. The limited experience with them has not warranted their extensive use, and so far the use of these machines has been confined mostly to Illinois.

In the West, where coal seams are unusually thick, open pit extraction techniques find application. At many operations, large conventional road excavating and grading equipment find wide use. Tractor scrapers, and bulldozers, while generally used for auxilliary stripping, have recently been used for primary stripping.

Stripping with a Shovel: In a typical operation with a shovel, a coal seam, about 4 feet thick and overlaid by 120 feet of shales, sandstones, clays and limestones, is exposed by a 105 cubic yard bucket, 200 foot boom shovel [2]. Vertical drill holes 15½ inches in diameter spaced approximately on a 50 x 60 foot grid pattern, reach within 5 feet of the coal. Thirty to thirty-three 80 pound bags of ammonium nitrate fuel oil (ANFO) are loaded into each holed. Usually, three rows of holes are shot with delays between each row. As can be seen in Figure 5.2, at any one time, a pit width of 180 feet is maintained. Coal is loaded by a 9 cubic yard shovel from a 54 foot cut into four 100 ton trucks.

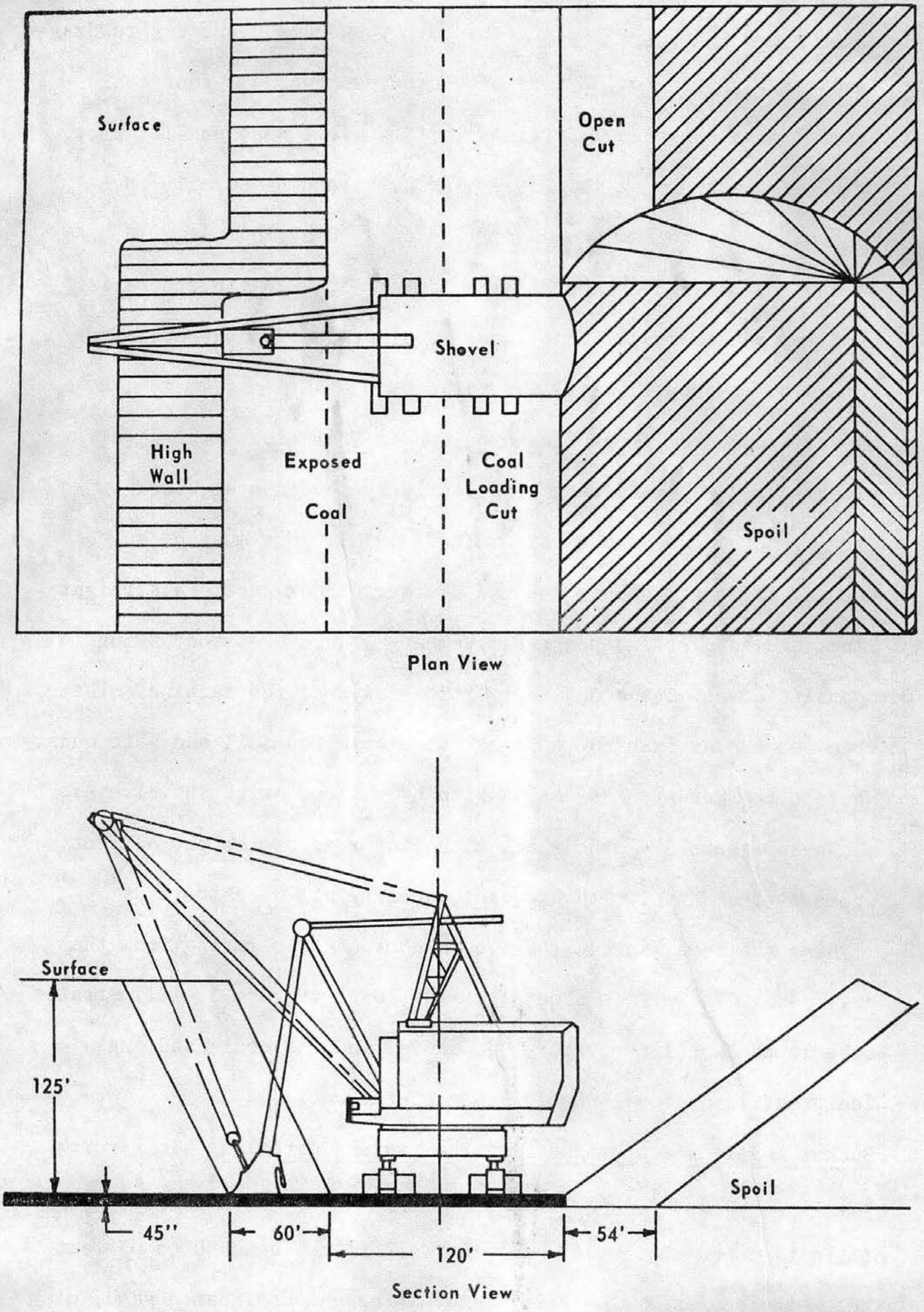


Figure 5.2. Plan section views of a Bucyrus-Erie 1950-B pit, [2].

Stripping with a Dragline: Figure 5.3 shows a 200 cubic yard dragline removing 120 to 130 feet of overburden over a 4-foot coal seam. It is capable of working a pit 250 feet wide and 185 feet deep. The overburden is prepared by bulk loading some $1\frac{1}{2}$ to $5\frac{1}{2}$ tons of ANFO into each hole, drilled on a 30 by 30 foot grid. A 14-cubic yard loading shovel with four to six 120-ton trucks is used for coal removal. The annual coal production expected from this mine is about 2.5 million tons.

Shovel and Bucket Wheel Excavator Tandem Operation: The wheel excavator can operate most efficiently by the frontal block digging method on benches of limited width. This must be so because the cutting boom and the discharge boom are in a straight line, and have no independent movement. Therefore, they swing in opposite directions about the vertical axis of the machine. The wheel excavator is used to remove the loose top soil and soft beds whereas the harder beds are handled by a large stick shovel. As shown in Figure 5.4, the wheel excavator removes the top 54 feet where as the shovel with a bucket capacity of 70 cubic yards removes the remaining 46 feet, both equipment operating from the coal seam. The pit is about $1\frac{1}{4}$ miles long. Figure 5.4 illustrates clearly the wheel excavator, the shovel and the coal handling equipment in a shovel-wheel tandem operation.

Bucket Wheel Excavator and Dragline Tandem Operation: In Figure 5.5 is shown a wheel excavator-dragline tandem operation in an Illinois mine. Both the equipment work from a bench 0 to 65 feet below the surface. The wheel removes the unconsolidated sand, clay

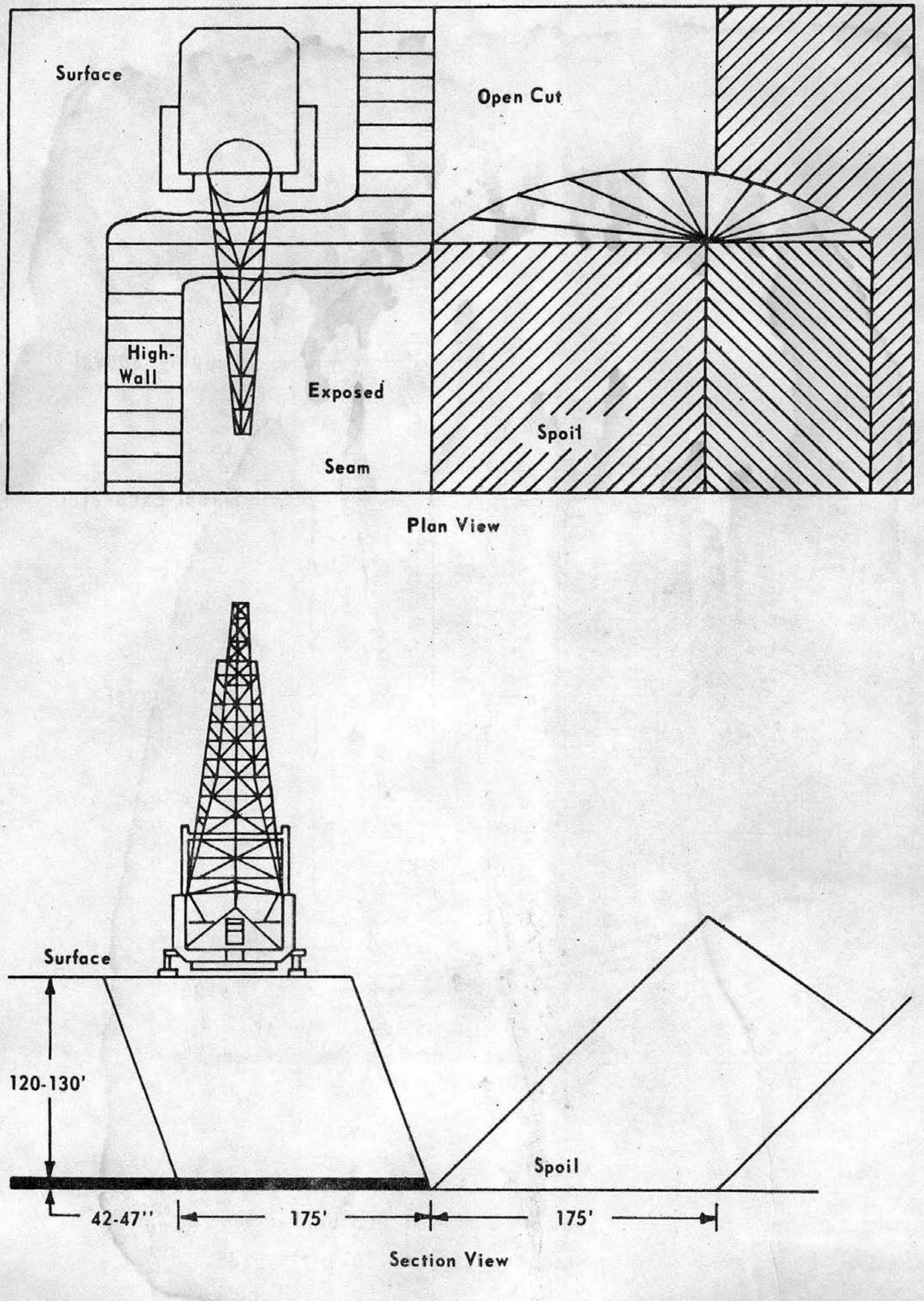


Figure 5.3. Pit layout at Bucyrus-Erie 4250-W operation, [2].

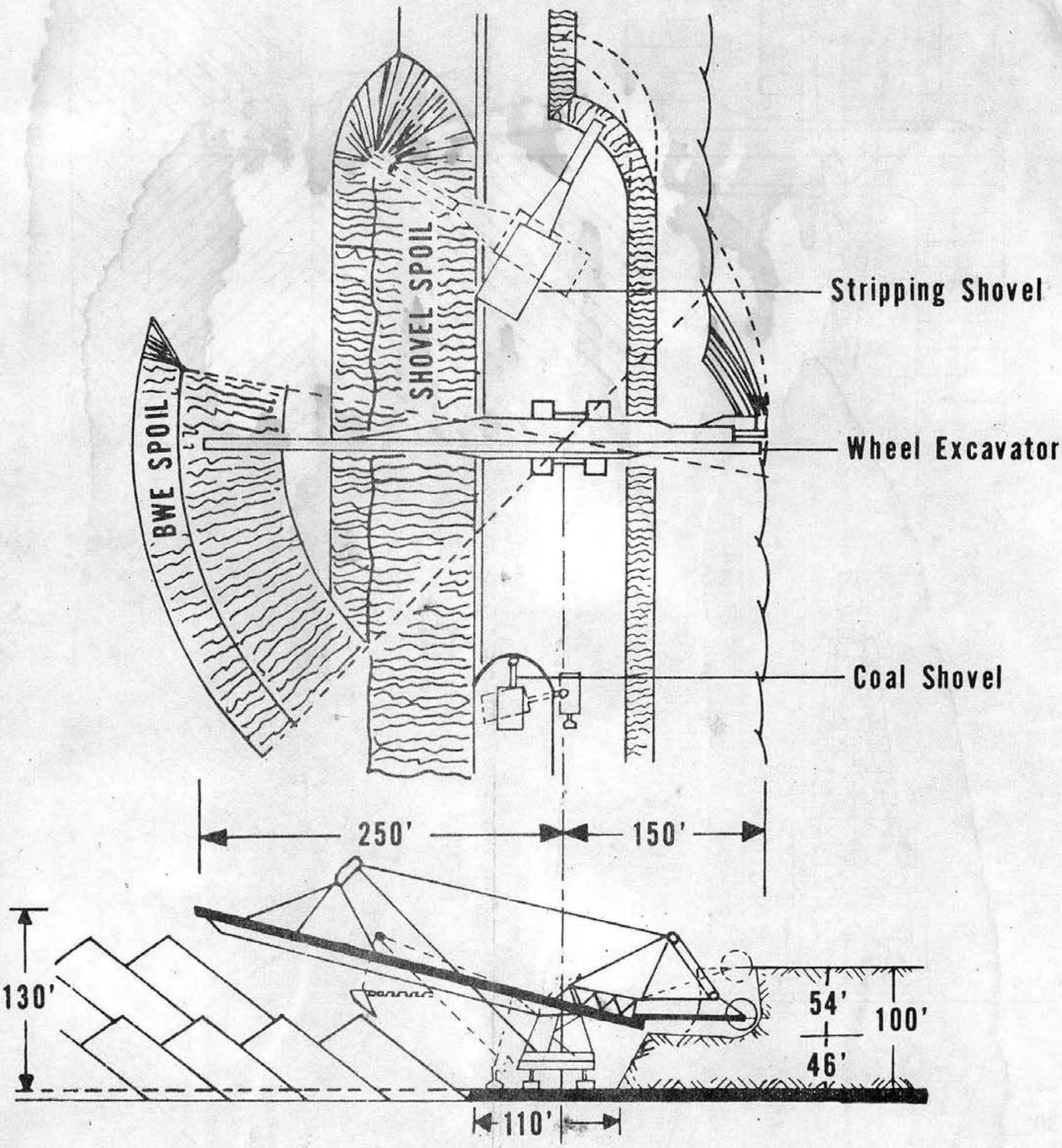


Figure 5.4. Pit layout at a shovel and bucket wheel excavator tandem operation in Illinois, [2].

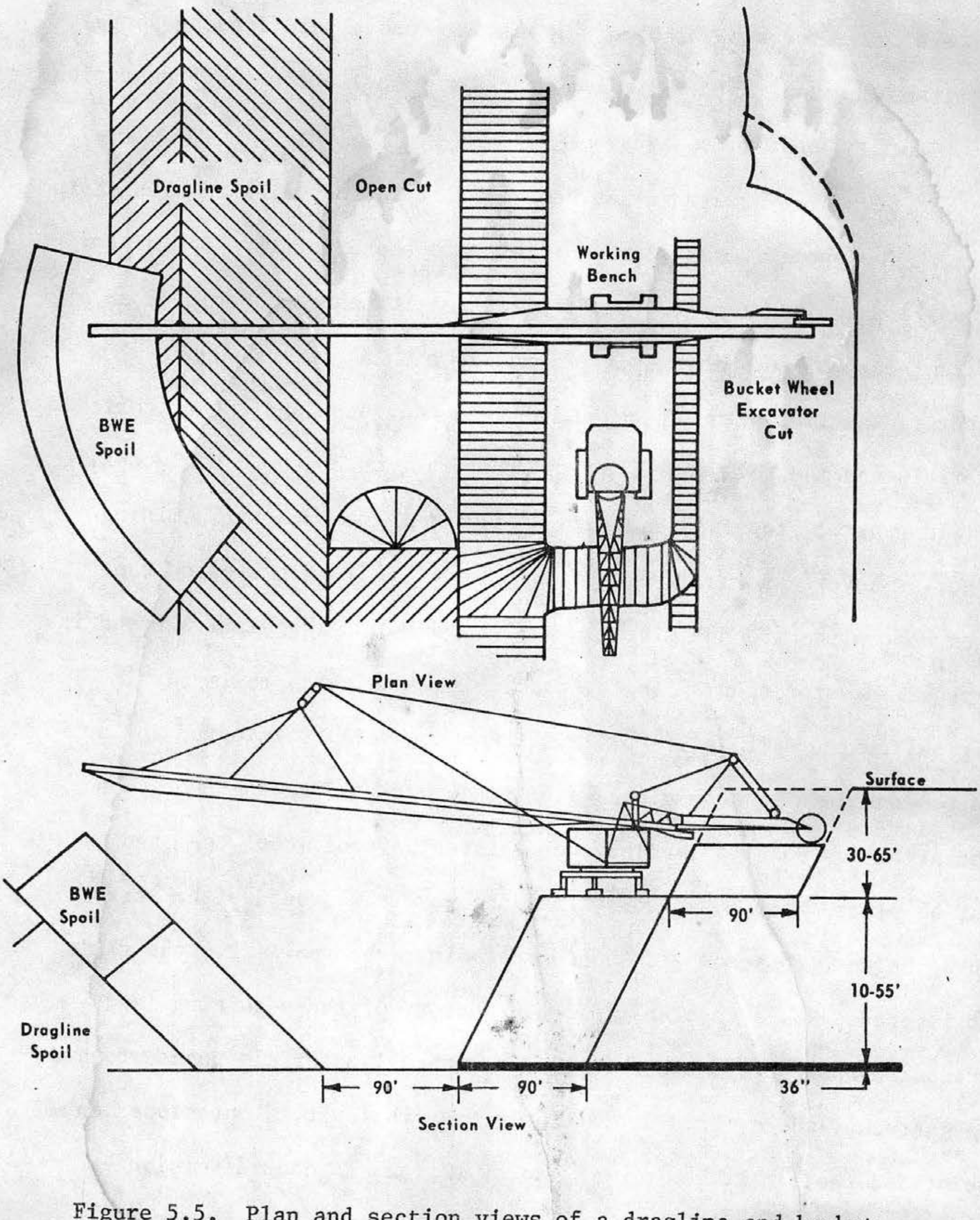


Figure 5.5. Plan and section views of a dragline and bucket wheel excavator in tandem operation, [2].

and gravel beds above the bench. Drilling ($10\frac{1}{2}$-inch diameter hole) is done on a 30-foot square gird to fragment the bench with NAFO explosive for removal by dragline. A 6-cubic yard loading shovel loads the coal onto 4-100 ton trucks for hauling to the preparation plant, $3\frac{1}{2}$ to 5 miles away.

The preceding treatment has been a brief introduction to area strip mining. The specific cases shown illustrate the diversity in mining methods and equipment. However, the reclamation aspect should be an inherent part of the mining method, rather than an afterthought. Proper reclamation planning can permit the adequate handling of toxic materials and the soil modification at a fraction of the ususal cost.

In general, the land and water pollution from area strip mining is not as severe as that from contour mines. Silt from erosion can often be confined to the mining area. The current legislative trend is to require restoration of the disturbed area to its approximate original contour with all spoil ridge and highwalls eliminated and no depressions left to accumulate water. Contour grading does not mean that all areas must be leveled, but rather the profile of the land must be placed back to approximately the way it was before the strip mining began. To accomplish contour grading, the spoil from the first cut is graded so as to blend into the contour of the adjoining land. Successive spoil piles are then graded with all materials pushed toward the last cut, where it is deposited in the final pit. Long slopes on the graded spoil must be interrupted by terraces and/or diversion ditches. All of the diversions and terraces must be constructed according to sound engineering principles and must end in suitable outlets.

Several states now require the operator to separate topsoil from the subsoil and to stockpile the two types separately so they will not be mixed during the excavation process. When mining is completed, the overburden can then be put back in its original sequence and revegetated to prevent erosion. Some operations remove the topsoil and immediately spread it on areas recently graded, thus handling the material only once. This provision insures that the best soil for plant growth is on top and not indiscriminately mixed with subsoils.

Some form of tillage of the site before planting is necessary. Any tillage measures must follow the contour of the slope and run parallel to the diversions or terraces. Chemical improvement of the soil in the form of liming and fertilizers is often needed for rapid establishment of vegetation.

5.1.2. Contour Mining Methods

Contour strip mining is practiced on rolling to very steep terrain. The conventional method of mining consists of removing the overburden from the mineral seam, starting at the outcrop and proceeding around the hillside (Figure 5.6). The cut appears as a contour line, thus, the name. Overburden is cast down the hillside and stacked along the outer edge of the bench (Figure 5.7). After the uncovered seam is removed, successive cuts are made until the depth of the overburden becomes too great for economical recovery of the coal. Physical limitations of equipment reach capacity and may also determine the strippable limit or cut-off point for mining. Contour mining creates a shelf or bench on the side of the hill. On the inside it is bordered by the highwall, ranging in height from a few feet to more

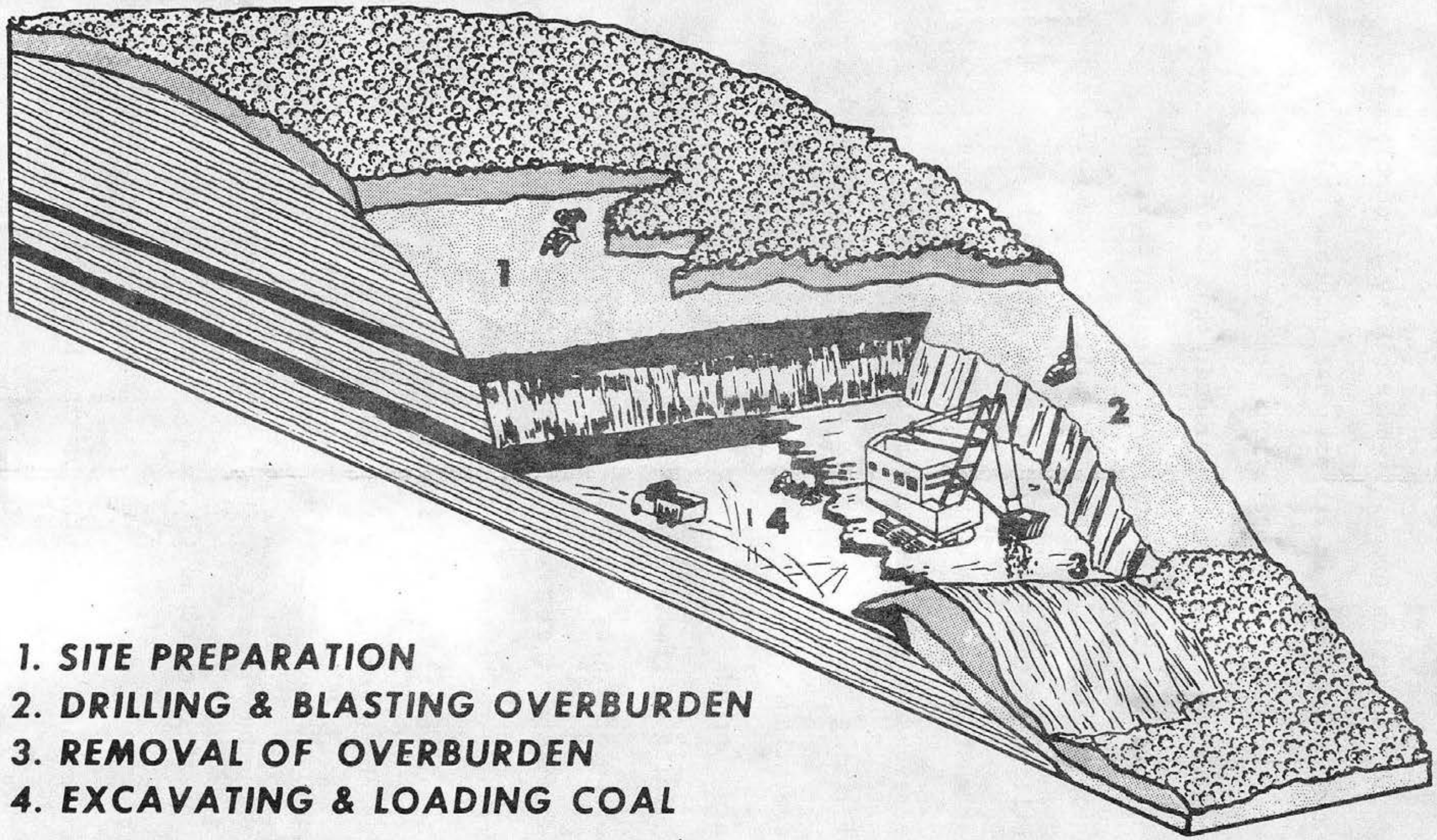


Figure 5.6. Contour strip mining, [1].

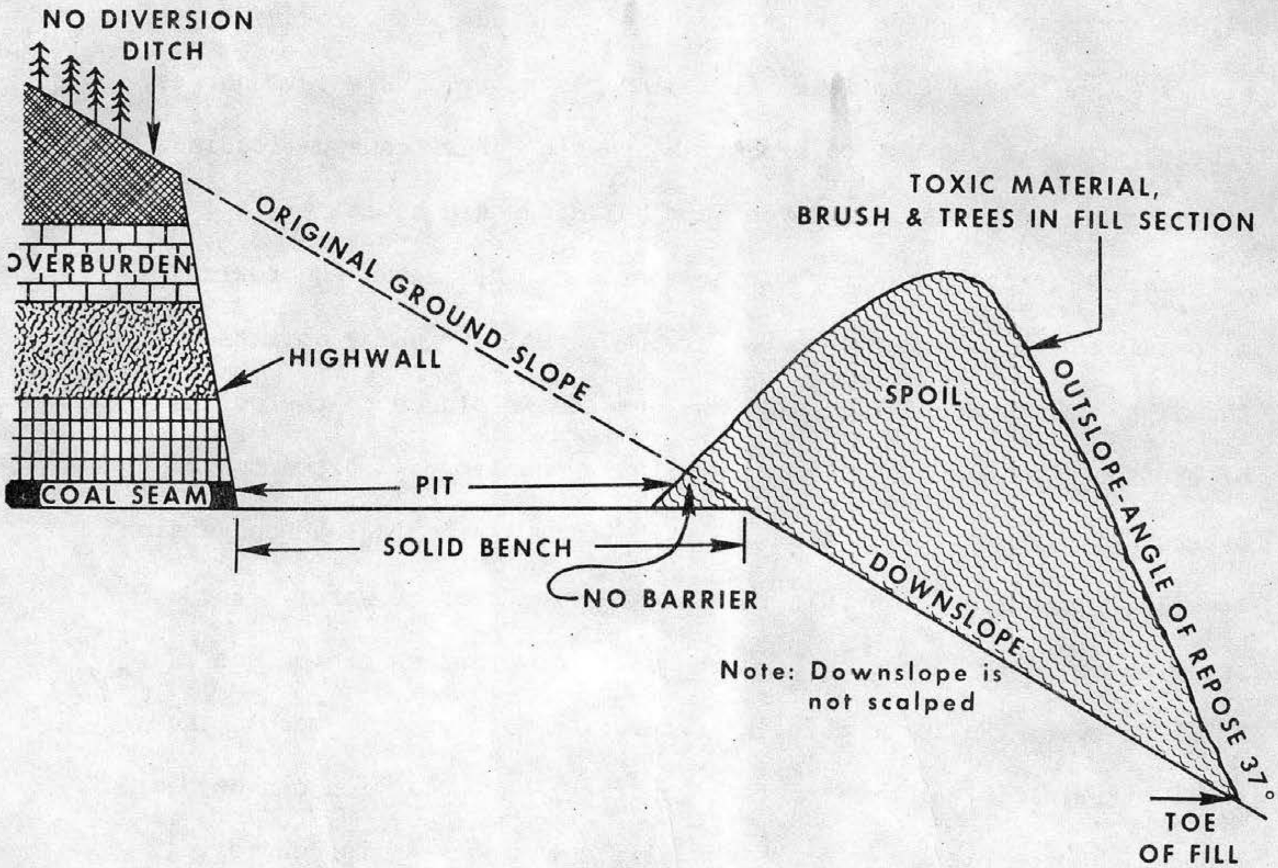


Figure 5.7. Conventional contour mining, [1].

than 100 feet; and on the outer side the pit is bordered by a high ridge of spoil with a precipitous downslope that is subject to severe erosion and landslides. Because of the landslide problem, several states have limited the bench width on steep slopes and forbid fill benches on slopes greater than 33 degrees.

Even with these precautions, landslides still occur. Sediment slides coming off mining operations have uprooted trees, covered highways, destroyed farm land, filled up reservoirs and water courses, clogges stream channels, covered fish-spawning beds, caused flooding of adjacent lands, and destroyed farm buildings and homes.

Another problem inherent in contour strip mining is the toxic materials in the overburden. During the normal stripping operation, the high quality overburden near the surface is placed on the bottom of the spoil pile and then covered with low quality and often toxic overburden, leaving toxic material exposed to weathering and conversion to soluble acids and minerals that are carried away by water. For a small extra cost, however, the high quality overburden can be set aside to cover the toxic material after grading. By this means, the toxic material is not subject to weathering, and pollution can be reduced. Moreover, cover crops are difficult to establish on toxic overburdens and therefore erosion damages occur. Erosion serves to prolong the mineral pollution problem by continuing to reveal new surfaces to weathering. However, when the toxic material is covered with a good material, cover crops can be grown to protect the surface.

Often in the excavation of a strip area, a natural drainageway is cut across. Unless the water is diverted around the mine workings, the water enters the mine area, where it may become polluted. Problems such as these have been averted by not stripping the drainageway or by placing control structures such as drop boxes and concrete flumes to handle the water.

Diversion ditches with good, controlled outlets should be constructed along the top of the highwall to keep water out of the workings. Water that does enter the pit must be properly handled. Strategically located sumps and pumps of capacity sufficient to discharge the water rapidly through plastic pipe across the disturbed areas, to natural drainwasy or to treatment facilities. This can reduce waterborne pollutant problems downstream. Under some conditions, wehre a workable system can be developed, it might be better to catch the water on the bench and control the discharge to the treatment facilities. Drainage patterns should be established in the pit area should be through well-designed outlets and must not overload the natural drainagemway. Proper management of water on the bench can markedly reduce the siltation and acid mine drainage problem.

It is critical that all efforts be made to locate underground mines adjacent to the surface mines. Cutting into abandoned or inactive underground mines can result in the discharge of large volumes of stored polluted water. The resultant, continued underground discharges into surface mining works during and following mining will aggravate the pollution problem. These conditions often make complete reclamation impossible, and in steep terrain, the underground mine can supply the water necessary for the development of slippage planes in the spoils. Where underground mines are adjacent to the proposed surface mines, barrier pillars should be left. When a deep mine is accidentally breached, the opening should be sealed as soon as possible by clay compaction, concrete, or any other method deemed necessary.

Removal and placement of the overburden are critical in environmental control. The nontoxic, nonacid, and fertile material should be stockpiled for later spreading or placed on top of the less desirable spoils already mined. The placement of the spoil should assure that long, steep slopes are avoided, that it is not on material subject to slippage, and that it does not produce high peaks difficult to regrade. In very steep terrain, such as in eastern Kentucky and southern West Virginia, the spoil should not be placed on the outslope, but hauled to a fill area designed for that purpose or placed on the bench behind the operation. The existence of ground water seeps and natural springlines must be determined prior to spoil placement or slippages may occur.

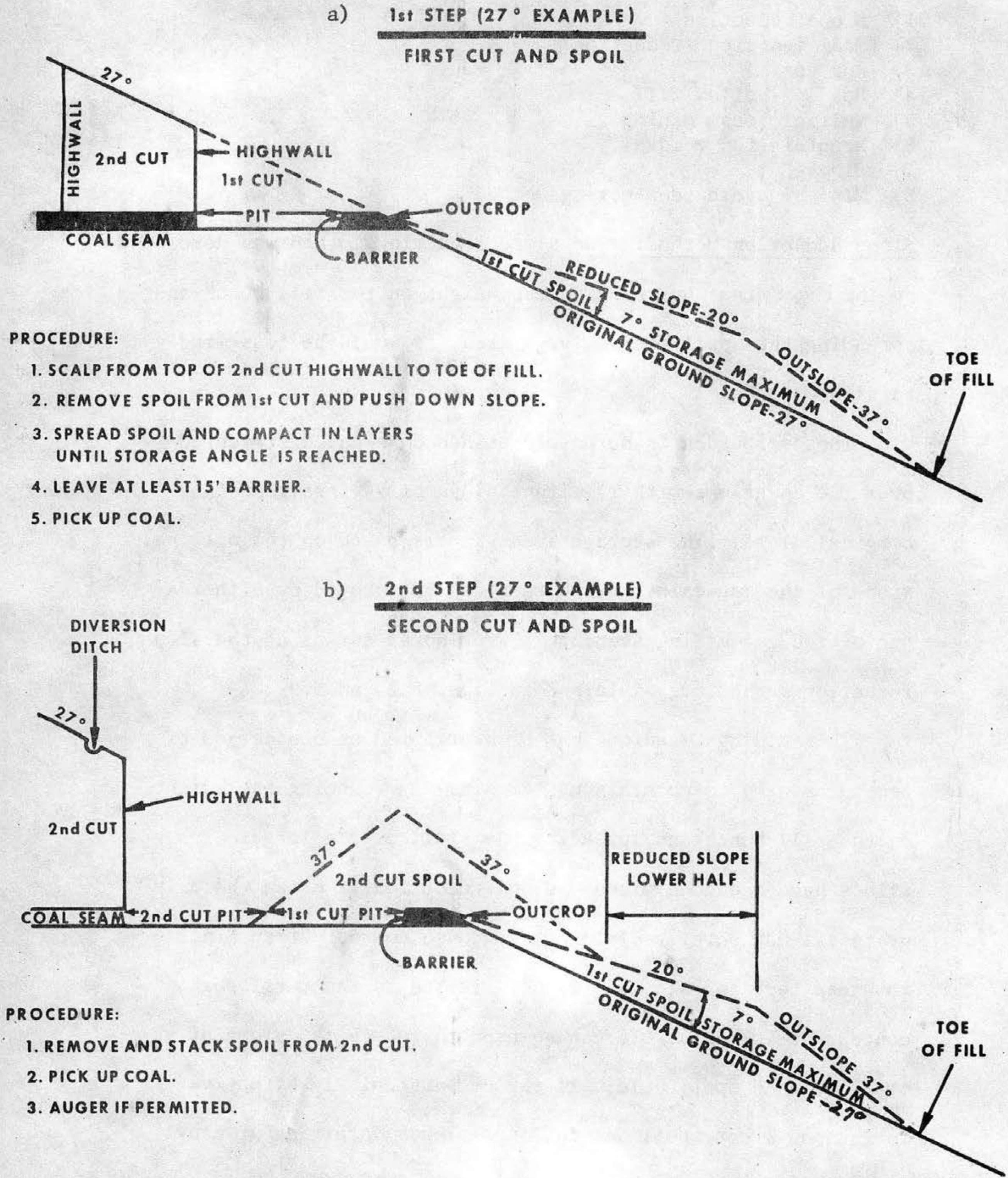
Contour strip mines disturb an area of the earth's surface much greater than the area covered by the seam of coal extracted, and have environmental problems not experienced in area mining. Because of this concerned Federal and State agencies along with the coal industry have been working together to develop mining methods which minimize the adverse effects on the environment while allowing the maximum recovery of coal. These new methods are not the final answer for all mining conditions and are being refined as more experience with varying conditions is gained. The new methods are the following:

1) Slope reduction
2) Modified slope reduction
3) Box-Cut
4) Head-of-hollow fill
5) Multiple seam mining
6) Mountain-top removal
7) Block-Cut
8) Minimal overburden-moving method

Slope Reduction Method: The slope reduction method was developed on the theory that by reducing the weight on the fill bench and spreading the spoil over a large area, it would be less likely to slide.

The overburden is purposely pushed down and distributed over the downslope with resultant slope of 7° less than the original slope. The storage area size is based on the original slope of the mountain. Overburden can be removed by either a one or two cut mining sequence. Procedures for using the slope reduction method are explained in Figs. 5.8 and 5.9.

This mining technique has been accepted as one method of contour mining in mountainous terrain. By reducing the weight on the fill bench and spreading the spoil over a larger area, slides have been minimized. Slope reduction is often the only practical method of reclaiming abandoned contour strip mines in steep terrain. Its use is not limited to the outslopes on contour strip mines. It can be used to reduce the slope of any oversteepened spoil pile. It may be particularly effective for use on steep spoil and tailings slopes occurring at many western mines.



Figures 5.8 a) & b). Slope reduction method, one and two cut method, [1].

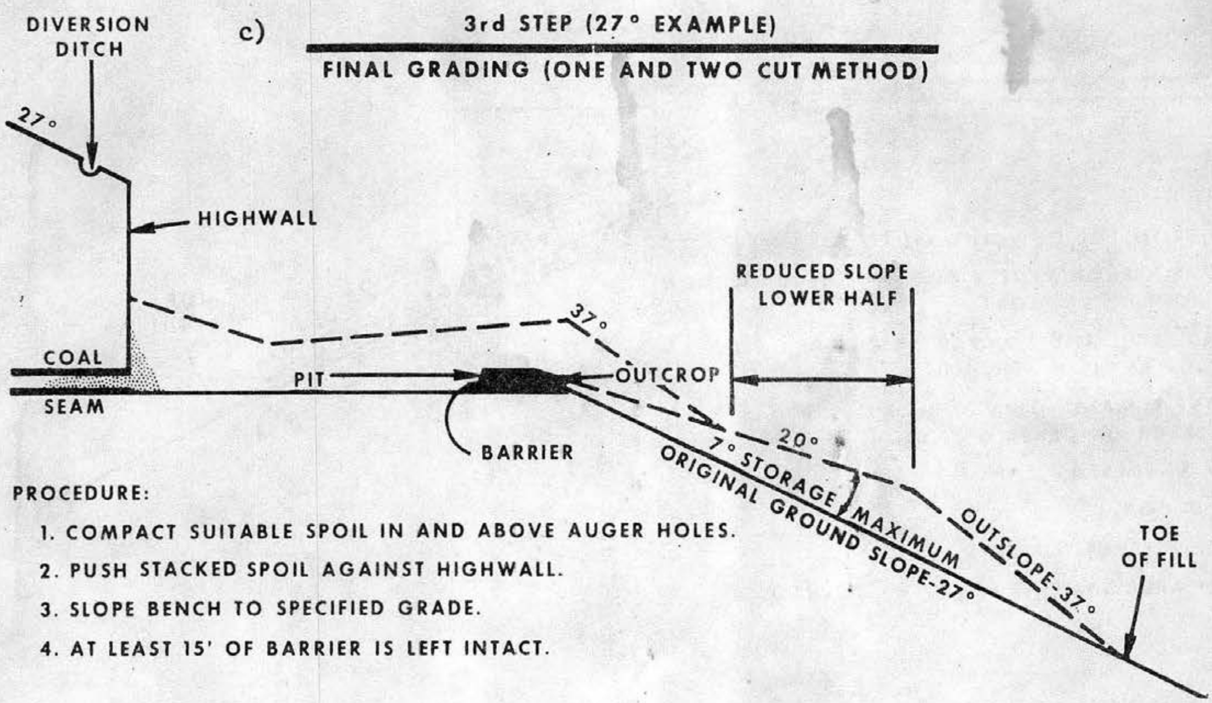


Figure 5.8 c). Slope reduction method, one and two cut method, [1].

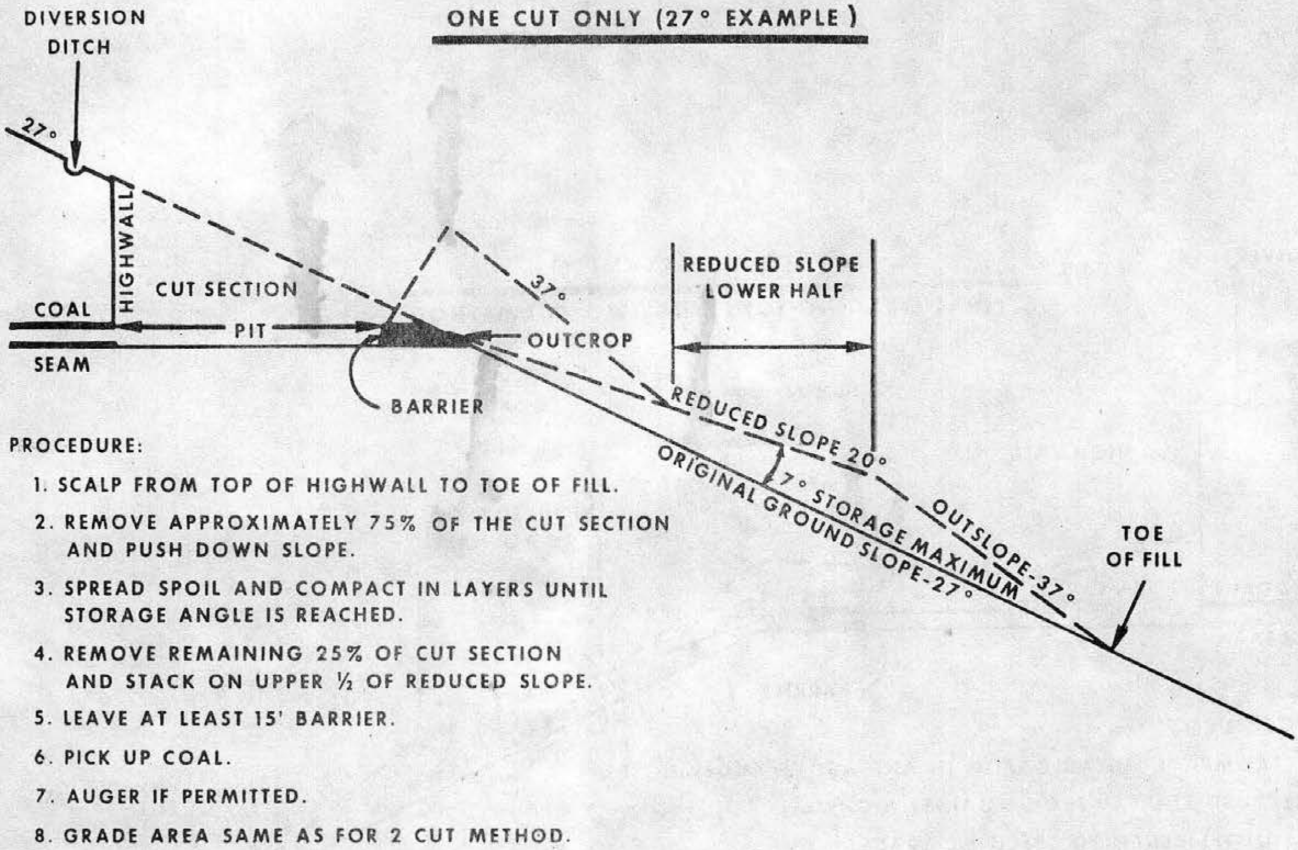


Figure 5.9. Slope reduction method, one cut only, [1].

Modified Slope Reduction Method: This method is also called parallel fill slope reduction and has no storage angle. Overburden is pushed down the slope and compacted in three-foot layers at the same angle as the original slope (see Figure 5.10).

Although parallel fill is still in the experimental stage, it may prove to be more successful than the storage angle method. No slides have developed, primarily because of the better friction plane which is more slide resistant.

Legislation at both the State and Federal level is becoming more stringent and making it illegal to push overburden beyond the solid edge of the bench and over the downslope. This type of restriction will ban the slope reduction method of mining. However, the theory of slope reduction has an interesting offshoot now being practiced by operators as an emergency measure when spoil begines to slide from the outslope. Bulldozers and/or pans are used to reduce the slide at its mid-section. The resulting profile approximates that of the slope reduction methods. Such an emergency measure is one practical and effective way to stop slides at an early stage when telltale tension cracks appear at the crest of the outslope [3].

Box-Cut Method, Two-Cut: The box-cut is one of the conventional contour strip mining methods. A box-cut is created by leaving an undisturbed section of the surface measured from the outer edge of the solid bench back toward the highwall. This barrier is at least 15 feet in width and provides a solid foundation on which

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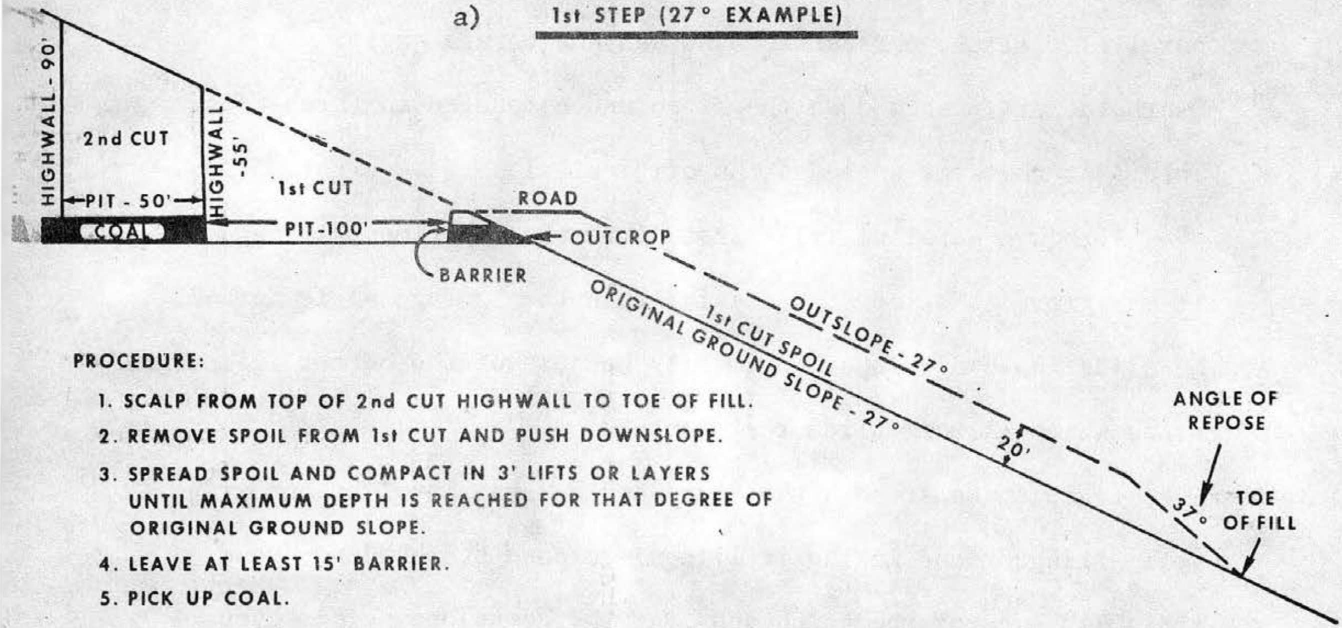


b) 2nd STEP (27° EXAMPLE)

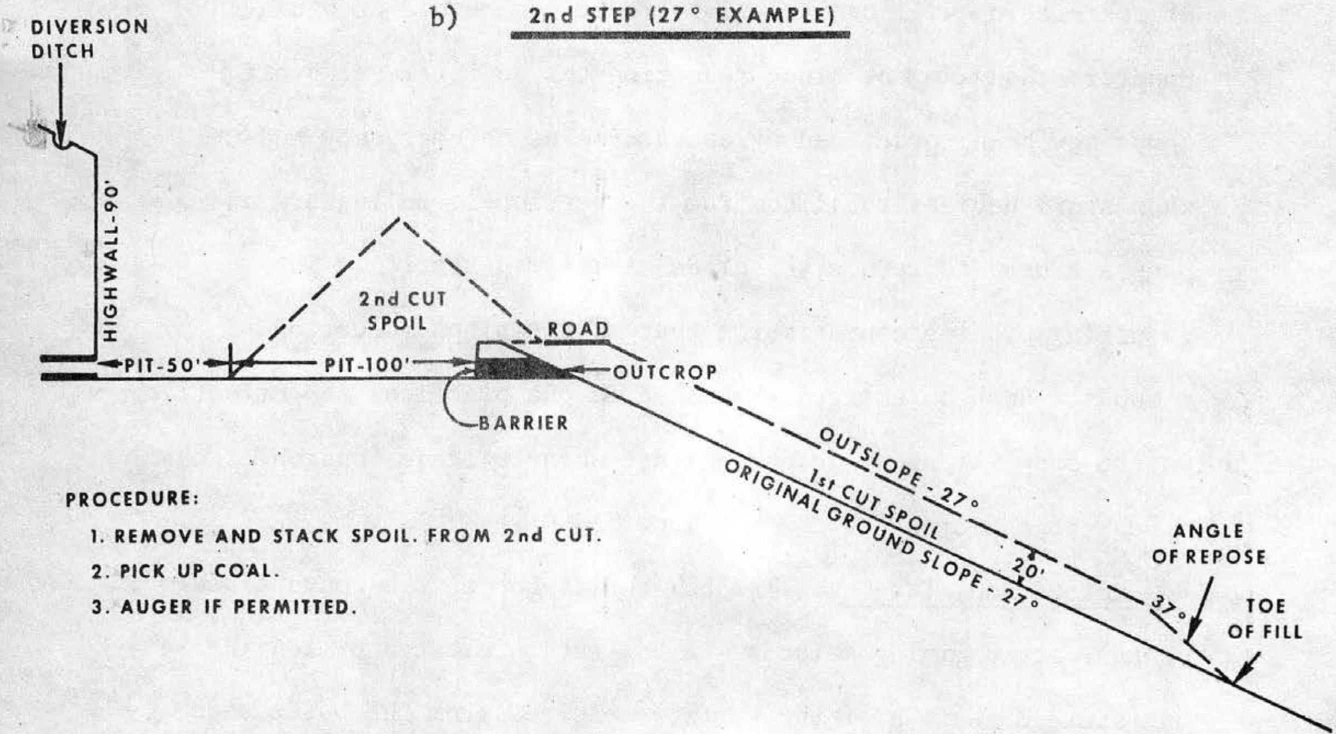


Figure 5.10 a) and b). Modified slope reduction, (parallel fill method), steps 1 and 2, [1].

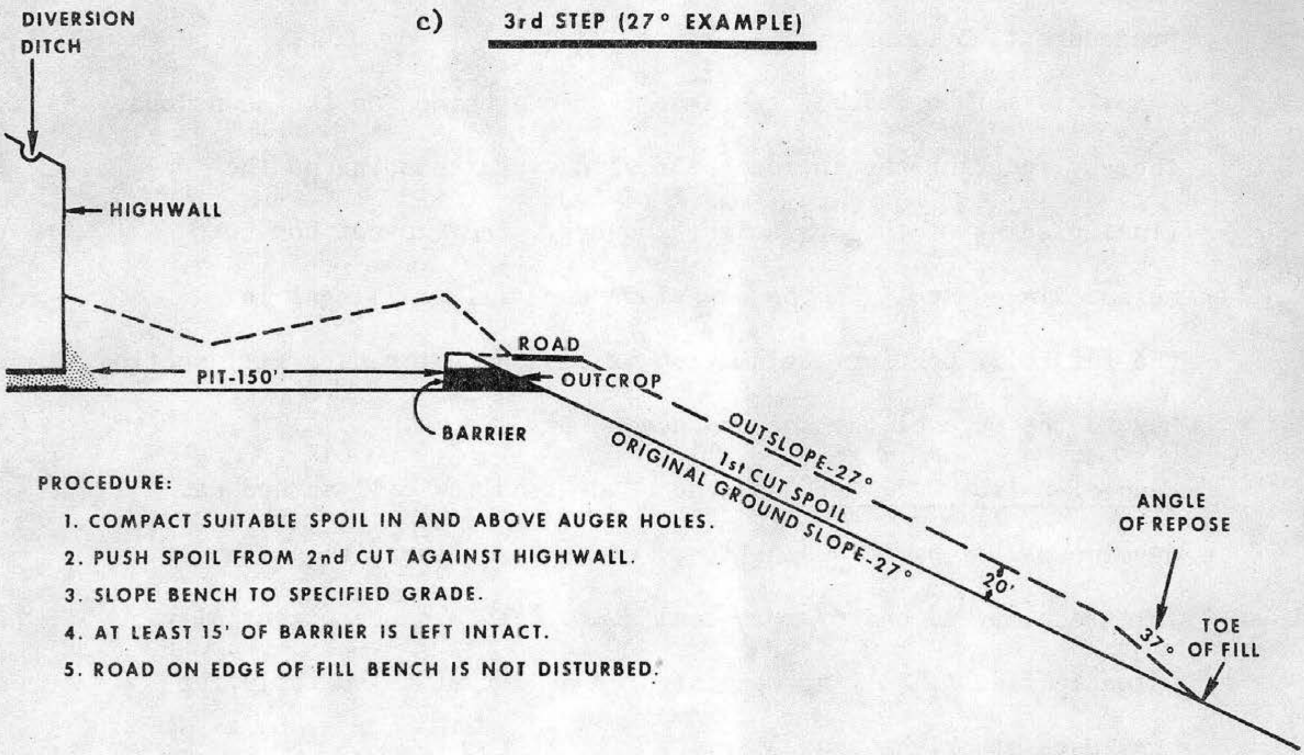


Figure 5.10 c). Modified slope reduction, (parallel fill method), step 3, [1].

to deposit spoil. It also helps to prevent water from running off the bench and percolating into the spoil on the downslope.

Basically, the two-cut box-cut method reverses the usual box-cut method by recovering the coal from the second cut first. This method was developed to prevent overloading the fill bench with second cut spoil and to make a more stable outslope. The procedure is outlined in Fig. 5.11.

This method reduces the amount of overburden on the downslope, thereby reducing the incidence of slides and speeding up the final grading of the operation. However, the two-cut box-cut method places spoil on the downslope and will be illegal in the future if pending legislation is passed that bans a fill section beyond the edge of the solid bench.

Head-of-Hollow Fill Method: The head-of-hollow fill method was developed to improve aesthetics, reduce landslides, allow for full recovery of one or more coal seams, and produce potentially valuable flat to rolling mountain top land that is suitable for many uses other than forestry.

The head-of-hollow fill method provides storage space for spoil from the removal of entire mountain tops and is also used as a waste area for overburden from contour benches. In the past, as the top coal seams were worked on the contour with a rim cut, islands of mountain land were left with no access. Many of these isolated areas of land left from previous mining operations are now being removed.

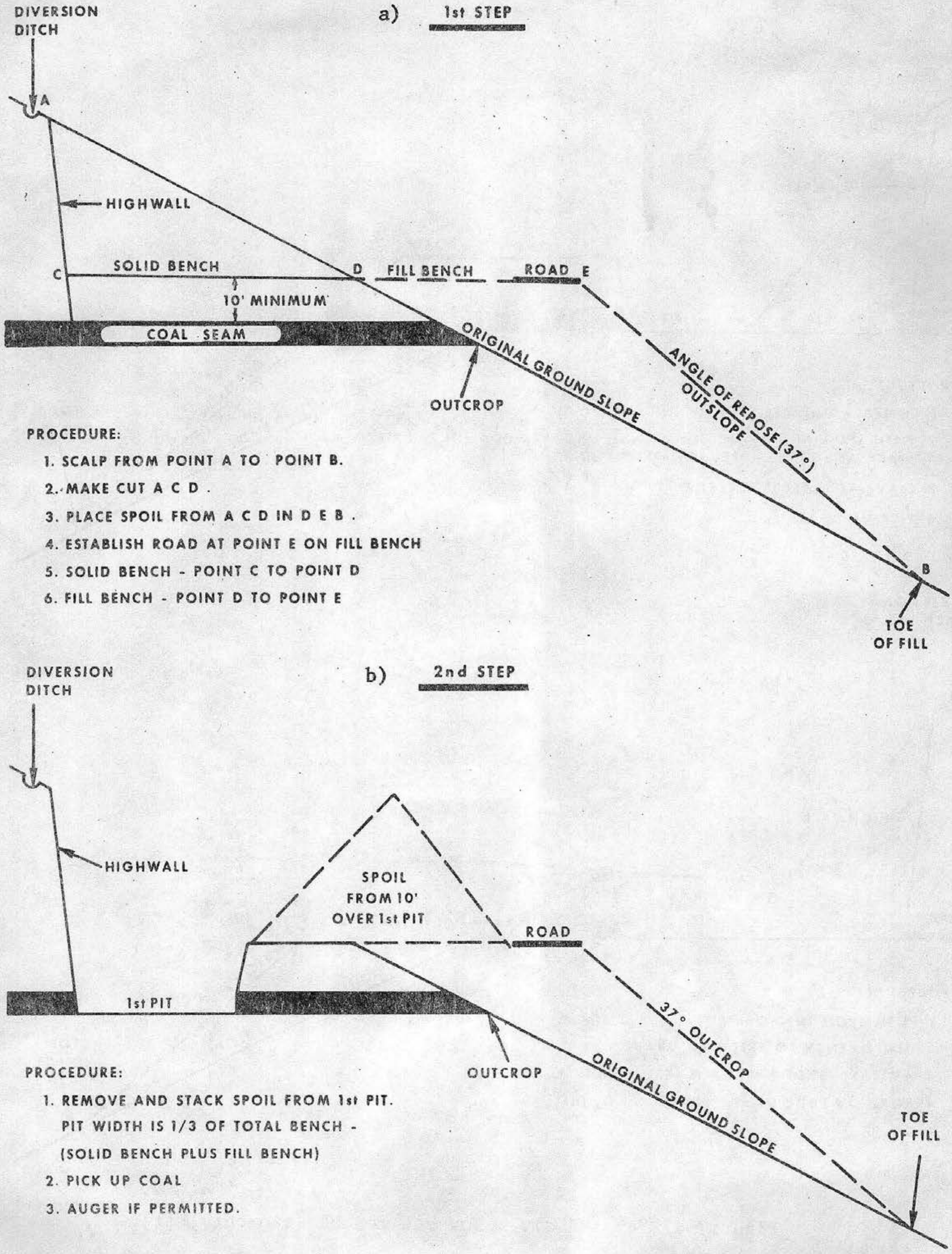
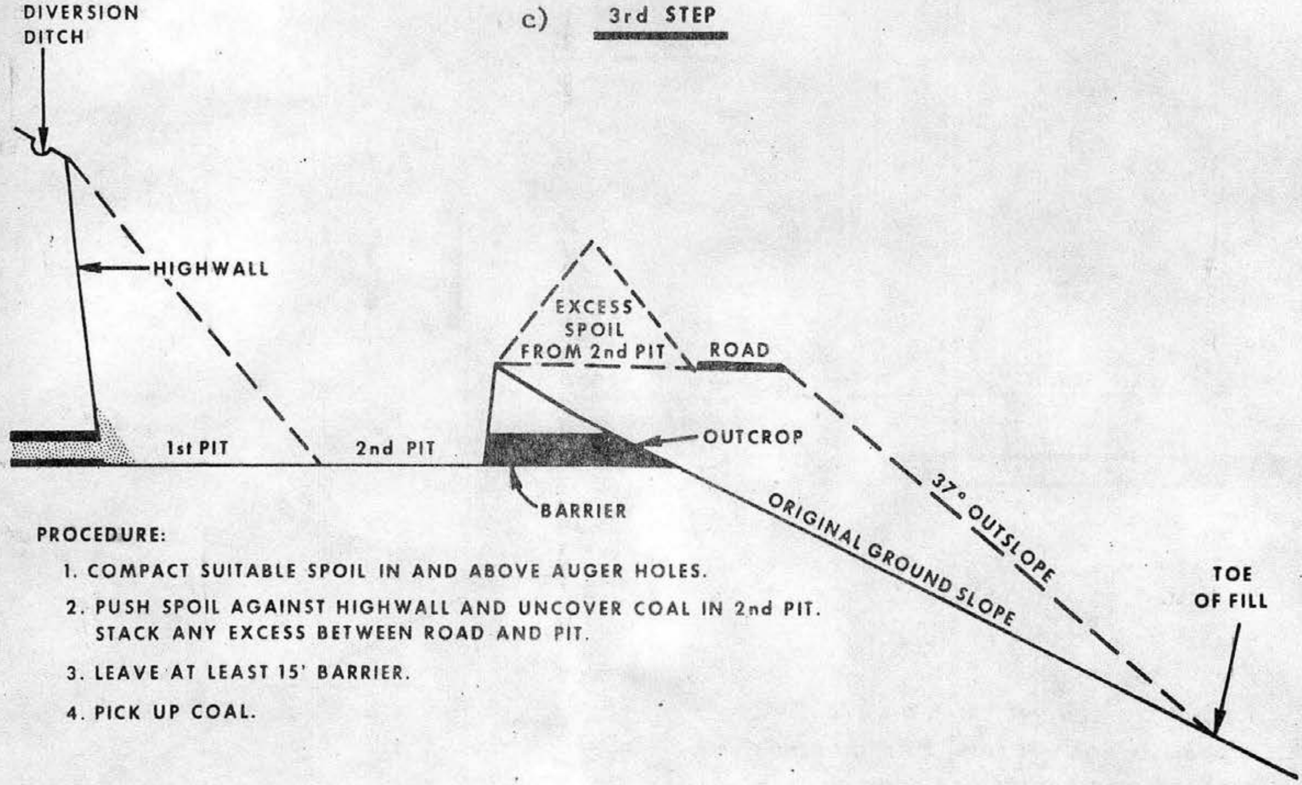


Figure 5.11 a) and b). Box-cut method (two-cut), [1].

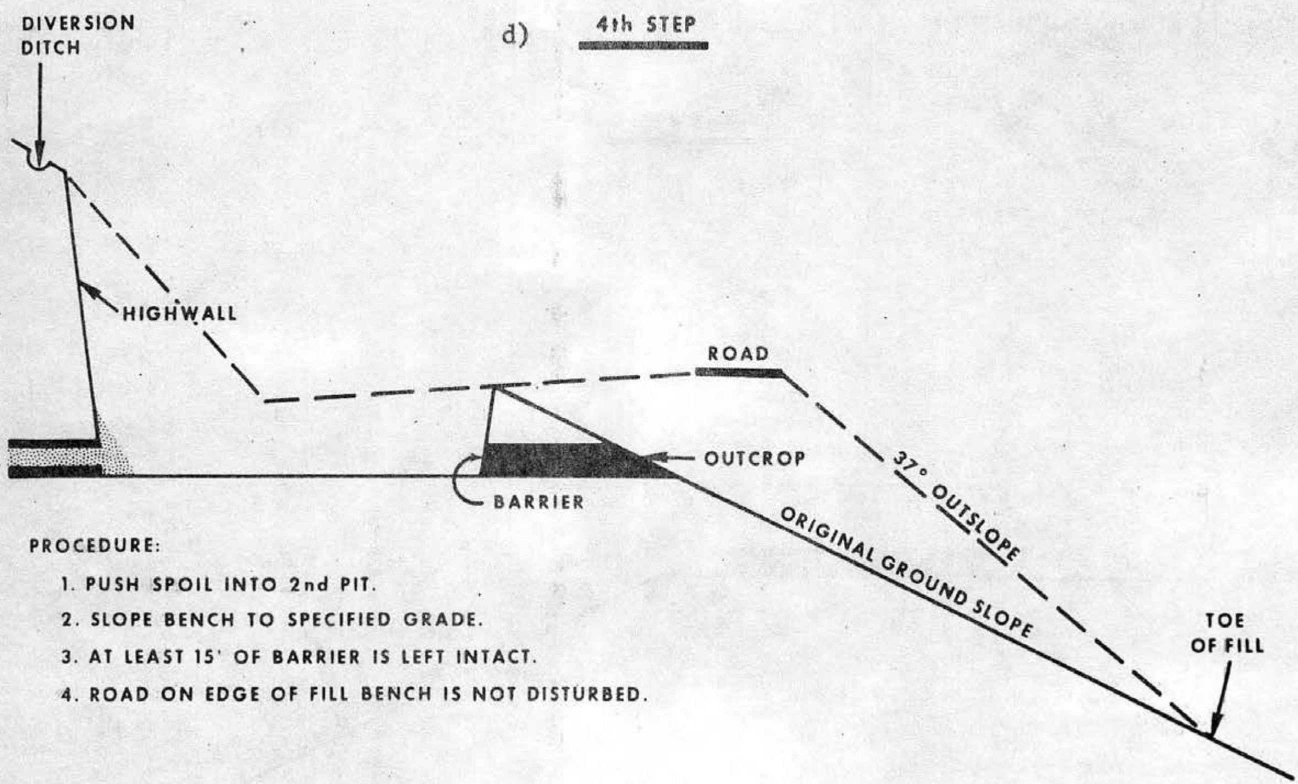
c) 3rd STEP



PROCEDURE:

1. COMPACT SUITABLE SPOIL IN AND ABOVE AUGER HOLES.
2. PUSH SPOIL AGAINST HIGHWALL AND UNCOVER COAL IN 2nd PIT. STACK ANY EXCESS BETWEEN ROAD AND PIT.
3. LEAVE AT LEAST 15' BARRIER.
4. PICK UP COAL.

d) 4th STEP



PROCEDURE:

1. PUSH SPOIL INTO 2nd PIT.
2. SLOPE BENCH TO SPECIFIED GRADE.
3. AT LEAST 15' OF BARRIER IS LEFT INTACT.
4. ROAD ON EDGE OF FILL BENCH IS NOT DISTURBED.

Figure 5.11 c) and d). Box-cut method (two-cut), [1].

Narrow V-shaped, steep-sided valleys that are near the ridge top, and are free of underground mine openings, seeps or wet weather springs, are selected for filling. The size of the selected valley must be such that the overburden generated by the mining operation will completely fill the treated head of hollow (valley).

The procedure to follow is (See Figure 5.12):

1. Scalp the vegetative cover from the area on which the spoil is to be deposited.

2. Remove and store topsoil.

3. Build French drains in all natural drainways that have been deepened by bulldozers, forming a continous chain from the upper end of the valley at the mined bench, down to a point several feet below the toe of the base fill layer. These rock drains will provide for internal drainage of the fill, and allow any water to percolate out instead of saturating the spoil and causing slides. The main drainway should be a minimum of 15 feet in width and composed of rock with a minimum dimension of 12 inches.

4. After internal drainage is provided, the fill is placed in compacted lifts or layers beginning at the tow of the fill. All material is deposited in uniform horizontal layers parallel with the proposed final grade and is compacted with haulage equipment. The thickness of the layers should not exceed the maximum size of the rock used as fill material and in any case not be over four feet. Layering continues until the top of the fill is slightly higher than the established bench level remaining after the coal has been removed. This slope should be no greater than 3 percent.

5. The center of the completed fill is crowned so that drainage will be toward the highwall or bench level adjacent to it and then to a safe outlet away from the toe of the fill.

6. The face of the fill resembles stair steps progressing from the base layer to the top of the fill. Each layer is a slightly crowned terrace that provided drainage to undisturbed land. The outer slope should be no steeper than 2 horizontal to 1 vertical.

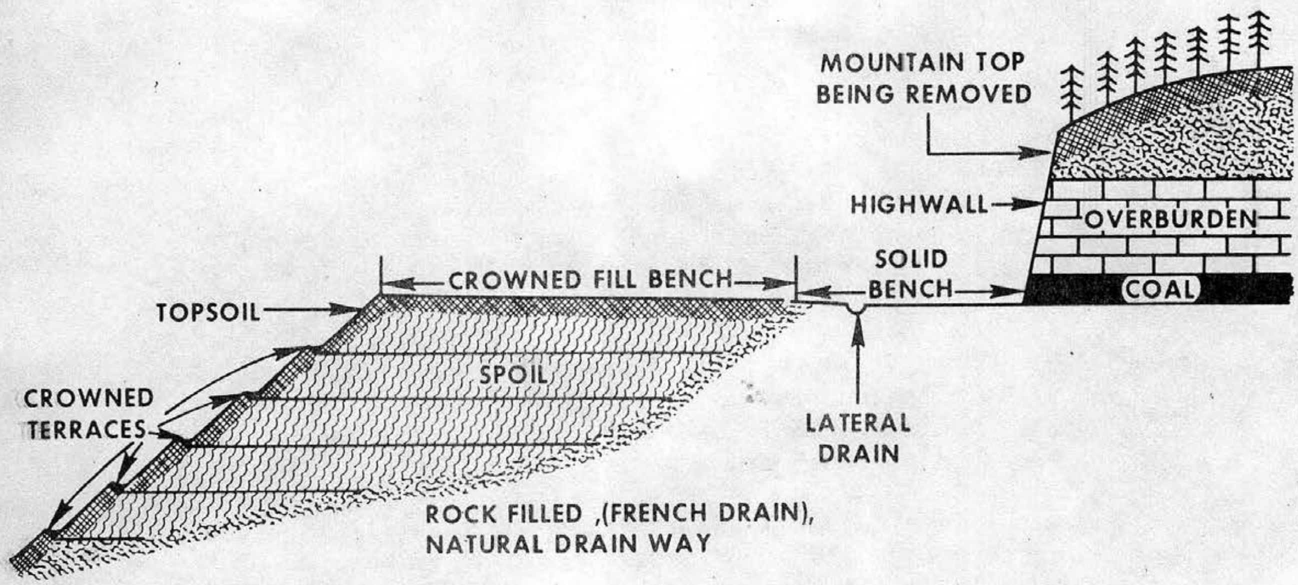


Figure 5.12. Head-of-hollow fill.

7. Check dams or silt control structures should be built downstream from the hollow fill.

8. Revegetation of the hollow fill face should progress as the fill height increases; hydroseeding is a preferred method.

If constructed according to design, stability of the fill can be expected. The horizontal and vertical pressures should provide adequate friction to prevent a failure in the fill. Several head-of-hollow fills have passed through five winters with no slides and little or no erosion. Instead of miles of unstable outslope, with its potential for slides and erosion, or islands of isolated land with no access, a large, stable, fairly level area can be constructed with this method.

Some operators have graded the face of the fill to approximately 22° from the horizontal, eliminating the crowned terraces. By mulching and revegetating immediately after grading, erosion has been held to a minimum. However, it has been found that long slopes must be interrupted with diversion ditches to control surface runoff and excessive erosion. These diversions should be installed at a minimum of every 50 feet in vertical height of the fill.

<u>Multiple Seam Mining</u>: Recoverable coal seams often lie close together. Multiple seam mining is the method in which more than one coal seam is strip mined at one time. This method is desirable, as all seams are mined in one systematic operation and it is not necessary to return at a later date and disturb the watershed again.

Method no. 1.--If the overburden from the upper seam will not reach the bench of the lower seam, treat each seam as a separate mining operation, mining the lower seam first. This bench may be used to store spoil produced during stripping of the upper seam.

Method no. 2.--If the overburden from the upper seam will reach the bench of the lower seam, mine the lower seam in advance of the seam above. Grading should be delayed on the lower bench in order to catch big rocks from the upper seam and bury them in the pit. In no instance can spoil from the upper seam extend more than one-half the distance from the highwall to the edge of the solid bench of the lower seam.

Method no. 3.--If both seams appear in the same highwall, separated by more than 25 feet, and two or more cuts are planned, the coal should be recovered from the bottom seam first. If the seams are separated by less than 25 feet, mine from the upper seam down, recovering both seams in one systematic operation (Figure 5.13). Lateral movement of the spoil is recommended.

<u>Mountain-Top Removal Method</u>: The mountain-top removal method of surface mining is an adaptation of area mining to contour mining for rolling to steep terrain. Where coal seams lie near tops of mountains, ridges, knobs, or knolls, they can usually be economically strip mined. The entire tops are removed down to the coal seam in a series of parallel cuts. Excess overburden that cannot be retained on the mined area is transported to head-of-hollow fills, stored on ridges, or placed in natural depressions. This mining method produces large plateaus of level,

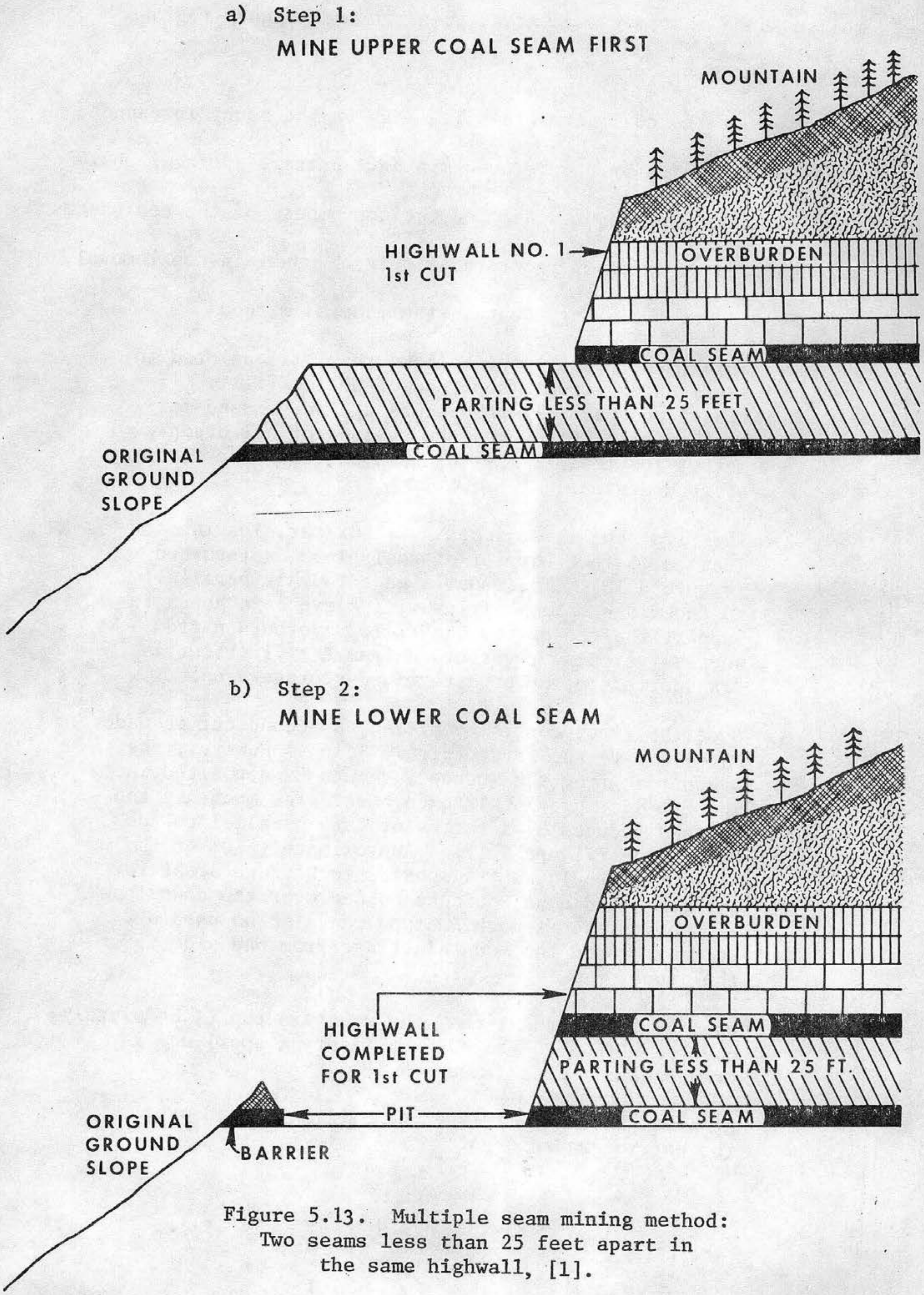


Figure 5.13. Multiple seam mining method: Two seams less than 25 feet apart in the same highwall, [1].

rolling land that may have great value in mountainous regions (Figure 5.14).

Many of the coal seams that lie high on the mountain cannot often be recovered by underground mining. Extreme surface subsidence, unsafe roof conditions, and the narrowness of the coal seams make these coal reserves recoverable only by mountain-top removal.

Procedures for using mountain-top removal method:

1. Select and prepare the hollows that will be used to store excess spoil (see Head-of-Hollow Fill). If ridges and natural depressions are to be used for spoil storage, they must be scalped of all organic matter and topsoil must be removed for later covering of graded areas.

2. The first cut is stripped as a box-cut, leaving at least a 15-foot barrier of coal bloom undisturbed (Figure 5.15). This cut is made roughly parallel to the ridge. The barrier will serve as a notch to support the toe of the backfilled overburden from successive cuts. Overburden from the first cut is transported to the predetermined storage area.

3. Once the first cut is completed, a second cut is made parellel to the first (Figure 5.16). However, the overburden from the succeeding cuts is deposited in the cut just previously excavated. The mountain top is thus reduced by a series of cuts parallel to the ridge line (Figure 5.17). Approximately 50% of the overburden would be transported to storage areas for disposal, and none would be pushed over the downslope. The mountaintop removal method can also be used by working around the mountain ridge from one side to the other.

4. When mining is completed, the mountain top is completely covered with a 20- to 40-foot layer of spoil and is graded nearly flat (Figure 5.18).

5. At least a 6-inch layer of topsoil is spread over the entire graded area.

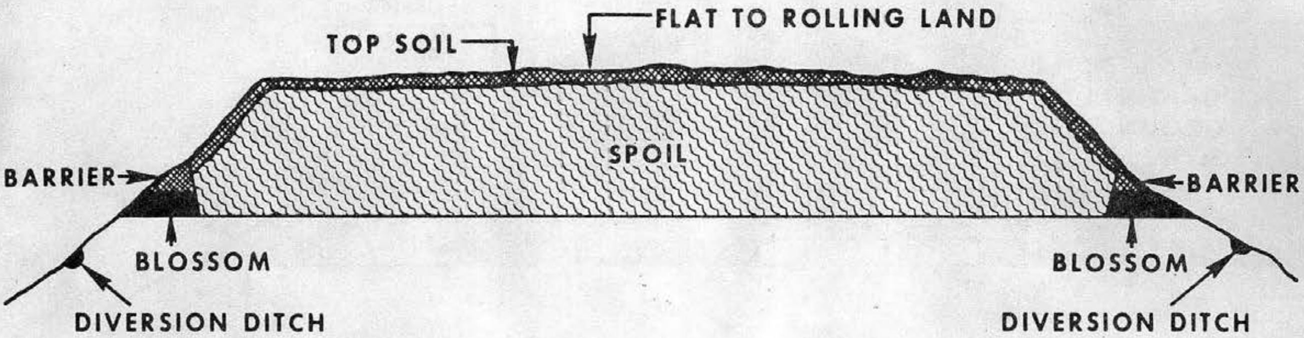


Figure 5.14. Mountain-top removal method:
Mountain top after final grading and topsoiling.

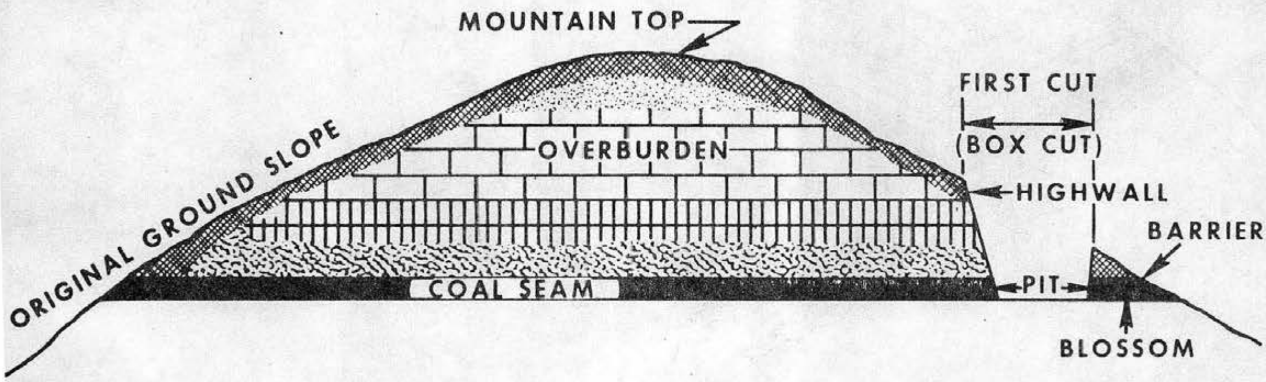


Figure 5.15. Mountain-top removal method:
First cut (box-cut).

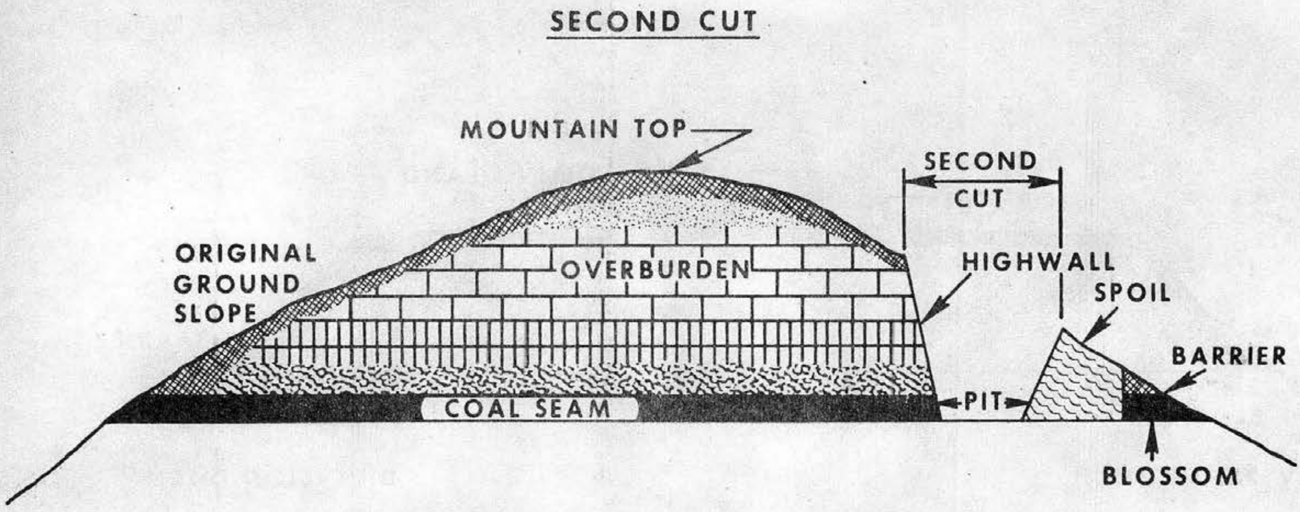


Figure 5.16. Mountain-top removal method: Second cut.

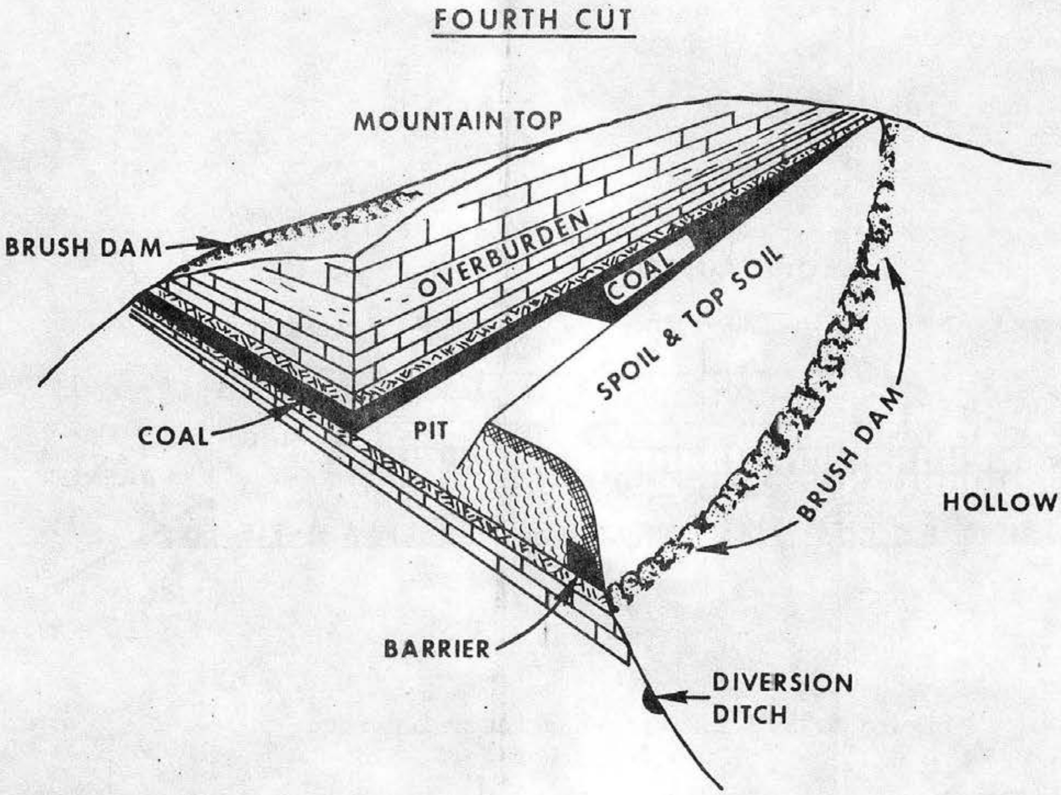


Figure 5.17. Mountain-top removal method: Fourth cut.

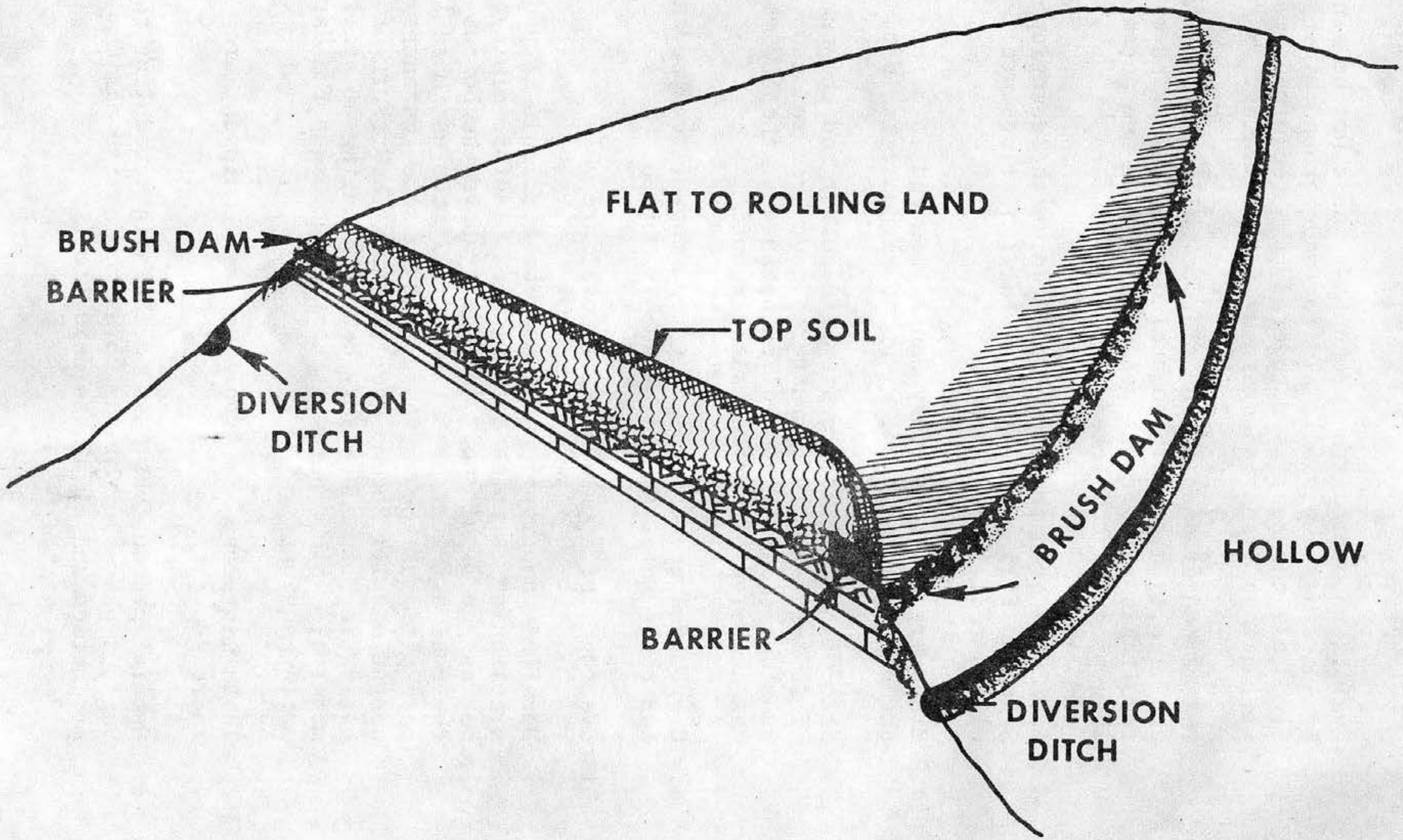


Figure 5.18. Mountain-top removal method:
Mountain top after final grading and topsoiling.

Benefits and advantages of using the mountain-top removal method have been demonstrated at producing mines in various states and are as follows:

1. Coal is recovered from areas that would not be mined because they are unsuitable for underground mining. Since all the coal is recovered, the reclaimed area will not be disturbed again by future mining.

2. The method creates large, flat to rolling areas that are vitally needed in mountainous regions. The end result has an enormous post-mining land use potential when properly completed.

3. Spoil has been totally eliminated on the downslope. Since no fill bench is produced, landslides are eliminated.

4. Mines area is completely backfilled and is more acceptable aesthetically, as no highwall is left.

5. Size of the drainage system is smaller and the number of sediment control structures have been reduced. Erosion is easily controlled because of the low velocity and quantity of surface water runoff.

6. Overburden is easily segregated, topsoil can be saved, and toxic material can be deeply buried.

Disadvantages of mountain-top removal are:

1. Detailed topographic maps must be available if proper preplanning is to be accomplished. Before mining begins the final spoil thickness above the bottom of the coal pit must be estimated. If the estimate is low, then pits must be narrowed, and in some instances the operation will become spoil bound. The result of underestimating is unnecessary double handling of spoil material, which increases cost and ties up the earthmoving equipment.

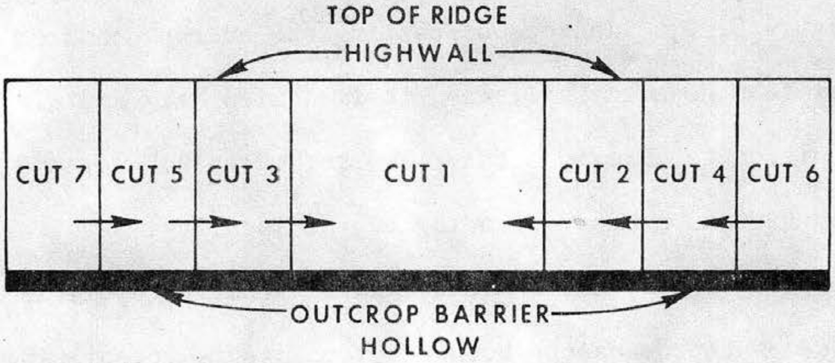
2. Investment costs for spoil haulage equipment are increased.

3. Special precautions must be taken in scheduling the various phases of mining so as to realize maximum production and eliminate dead time.

Block-Cut Method: The Block-cut method is a simple innovation of the conventional contour strip mining method for steep terrain (See Figure 5.19). Instead of casting the overburden from above the coal seam down the hillside, it is hauled back and placed in the pit of the previous cut. The method is not new and is known by various names, depending on the locality. Basically, the operational procedures are similar in that no spoil is deposited on the downslope below the coal seam, topsoil is saved, overburden is removed in blocks and deposited in prior cuts, the outcrop barrier is left intact, and reclamation is integrated with mining (Figures 5.20 and 5.21).

When beginning the mine, a block of overburden is removed down to the coal seam and disposed of. This first cut spoil can be placed above the highwall in some instances, or spread along the downslope as in conventional contour mining, or moved laterally and deposited in a head-of-hollow fill or ridge fill. The original cut is made into the hillside to the maximum depth that is to be mined. The width is generally three times that of the following cuts. After the coal is removed, the overburden from the second cut is placed in the first pit and the coal from the second cut is removed. This process is repeated as mining progresses around the mountain. Once the original cut has been made, mining can be continuous, working in both directions around the hill or in only one direction.

The cuts are mined as units, thereby making it easier to retain the original slope and shape of the mountain after mining.



PROCEDURE:

1. SCALP FROM TOP OF HIGHWALL TO OUTCROP BARRIER, REMOVE AND STORE TOPSOIL.
2. REMOVE AND DISPOSE OF OVERBURDEN FROM CUT 1.
3. PICK UP COAL, LEAVING AT LEAST A 15 FOOT UNDISTURBED OUTCROP BARRIER.
4. MAKE SUCCESIVE CUTS AS NUMBERED.
5. OVERBURDEN IS MOVED IN THE DIRECTION, AS SHOWN BY ARROWS, AND PLACED IN THE ADJACENT PIT.
6. COMPLETE BACKFILL AND GRADING TO THE APPROXIMATE ORIGINAL CONTOUR.

Figure 5.19. Block-cut method.

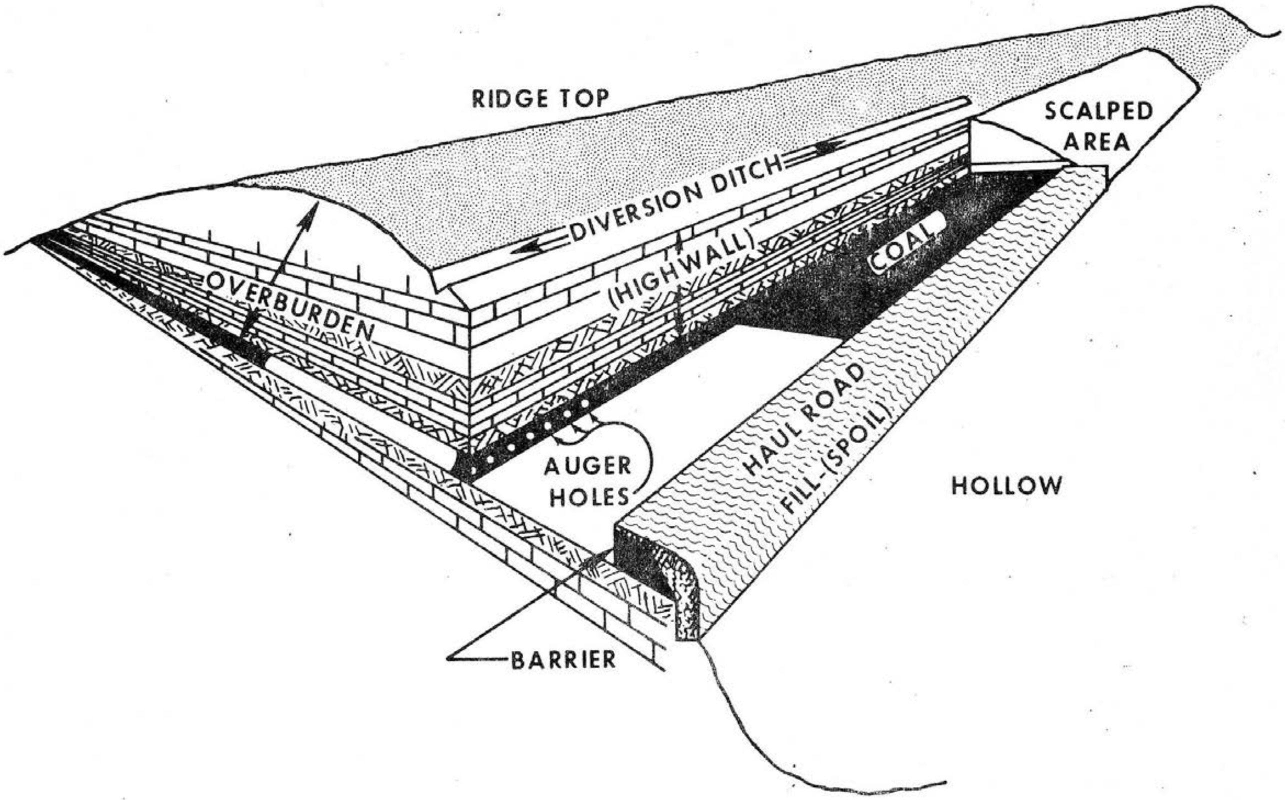


Figure 5.20. Block-cut method: Stripping phase.

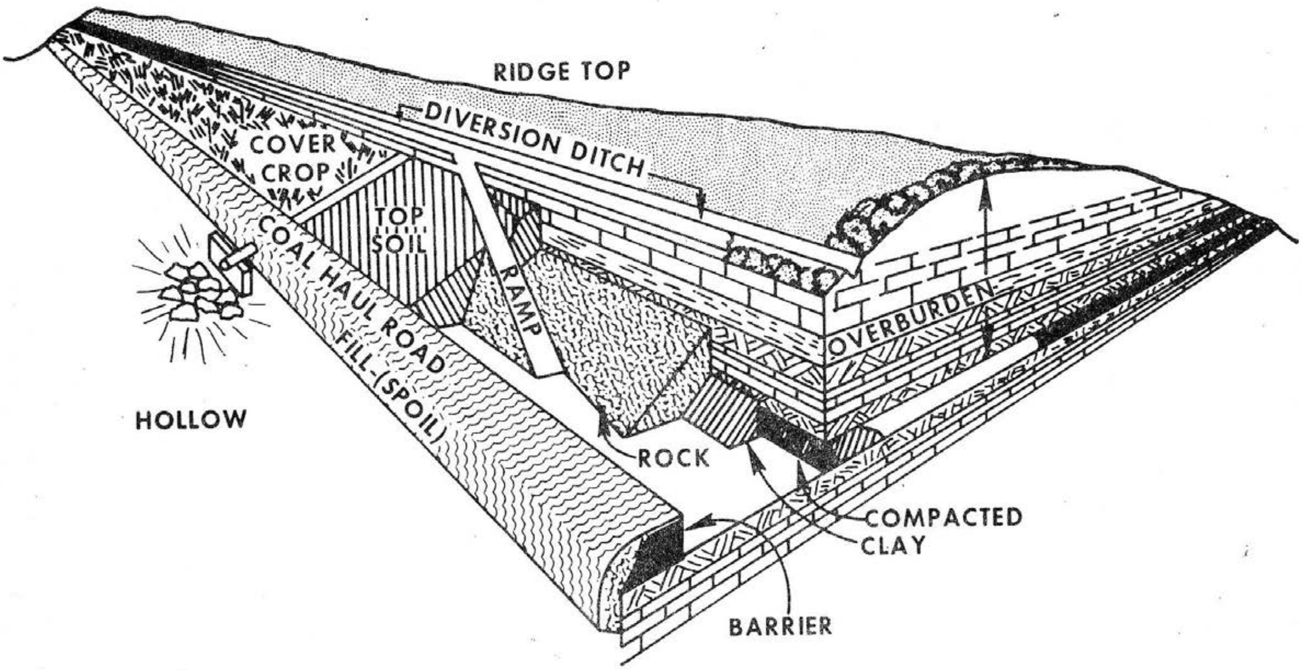


Figure 5.21. Block-cut method: Backfilling phase.

In all cuts, an unmined outcrop barrier is left to serve as a notch to support the toe of the backfilled overburden. Block-cut mining makes it possible to mine on slopes steeper than those being mined at present without the danger of slides and with minimal disturbance. Approximately 60% less total acreage is disturbed than by other mining techniques now in use. There is significant visual evidence that the block-cut method is less damaging than the old practice of shoving overburden down the side of the mountain resulting in permanent scars on the landscape. The treeline below the mined area and above the highwall is preserved. Results of the mining operation generally are hidden and cannot be seen from the valley below. This cosmetic feature is only one of the advantages that contribute to making this an acceptable steep-slope mining method.

Existing or pending State and Federal legislation makes it illegal to push overburden beyond the outcrop and over the mountain-side and thus bans the conventional type of contour strip mining. However, the block-cut or similar methods meet the criteria of this new legislation and allow for recovery of coal reserves in mountainous regions that would otherwise be unmineable.

The block-cut method is no longer experimental and is now operational in several States. Enough inforamtion is available from active operations to show this method to be potentially feasible from an economic and environmental standpoint.

Benefits and advantages of the block-cut method over conventional contour strip mining have been demonstrated at producing mines under varying conditions and are [1]:

1. Spoil on the downslope is totally eliminated. Since no fill bench is produced, landslides have been eliminated.

2. Mined area is completely backfilled, and since no highwall is left, the area is aesthetically more pleasing.

3. Acreage disturbed is approximately 60% less than that disturbed by conventional contour mining.

4. Reclamation costs are lower, as the overburden is handled only once instead of two or three times.

5. Slope is not a limiting factor.

6. The block-cut method is applicable to multi-seam mining.

7. At present, this method does not require the development of new equipment. As new mining technology develops, however, modified or new types of equipment may be needed.

8. Regular explosives are used, but blasting techniques had to be developed to keep shot material on the permit area.

9. Bonding amounts and acreage fees have been reduced.

10. Size of the disturbed area drainage system is smaller.

11. Size and number of sediment control structures have been reduced. Total life of structure usefulness is increased.

12. No new safety hazards have been introduced. However, with the increased number of pieces of moving equipment in a more confined area may negate this point.

13. Revegetation costs have been considerably reduced and it is easier to keep the seeding current with the mining. Bond releases are quicker.

14. Erosion, acid mine drainage, and siltation are significantly reduced and more easily controlled because of concurrent reclamation with mining.

15. Total amount of coal recovered is equal to that recovered by conventional methods.

16. Overburden is easily segregated, topsoil can be saved, and toxic materials can be deeply buried.

17. Equipment, materials, and manpower are concentrated, making for a more efficient operation.

18. The method allows for early removal of equipment from the operation and placing it back in production at another site.

Disadvantages of the block-cut method are:

1. Complicated and time-consuming methods of drilling and blasting to maintain control of the overburden and get proper fragmentation for the particular types of equipment being used in spoil removal.

2. Economics may limit use of this method; i.e., thin seams of steam coal cannot be recovered profitably if the overburden must be shot.

3. Special precautions must be taken in scheduling the various phases of mining and reclamation so as to realize the maximum recovery of coal and at the same time eliminate any dead time for equipment.

4. It is very important that the location of the initial box-cut be properly selected. In some areas there will be no place to back haul the material taken at the beginning of the block-cut or to dispose of the excess spoil at the end of the operation. Head-of-hollow fill is not always possible, as it can only be done in a restricted set of circumstances.

5. Long-term environmental consequences are not known and will require a monitor program of a pilot block-cut operation to determine if stream siltation and mineralization can be eliminated.

6. Investment costs for spoil haulage equipment are increased. Some small mines cannot afford this additional expense.

7. The block-cut method develops no broad bench that has a high land use potential in mountainous terrain. No access is left for forest firefighting crews, timbering operations, or recreational purposes.

8. Augering must be conducted concurrently with mining.

Perhaps the most salient feature of block-cutting is that the removal of the overburden and the reforming of the original contour by backfilling are integral processes (Figures 5.22 and 5.23). As a result, the method tends to reduce many of the associated environmental impacts that occur by other methods. This new mining technique has been accepted as one of the most significant break-throughs made in contour mining in mountainous terrain.

Minimal Overburden-Moving Mining Methods: All surface mining methods previously discussed depend on removing massive quantities of overburden to recover the coal. Some underground mining techniques and machinery may possibly be adapted for surface mining of coal at shallow depths. Coal companies are interested in new ideas for extracting coal from a highwall without moving overburden and without sending men underground.

Highwall mining method--Highwall mining is an automated variation of an underground mine cutting machine worked through the highwall following the stripping. It has been used only to a limited extent and needs further development to eliminate operational problems. The cutting machines are remotely controlled continuous miners designed to enter highwalls and remove coal up to 1,000 feet in depth at a rate of 3,000 tons per day. New entries are made a predetermined intervals along the outcrop until the end of the property is reached.

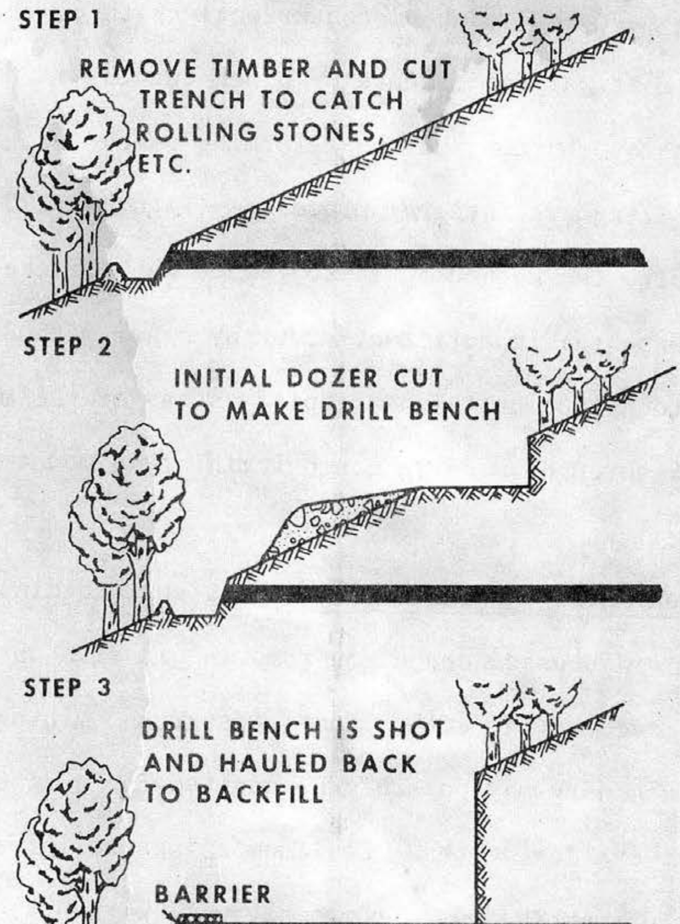


Figure 5.22. Block-cut method:
Controlled placement of spoil, steps 1, 2, and 3.

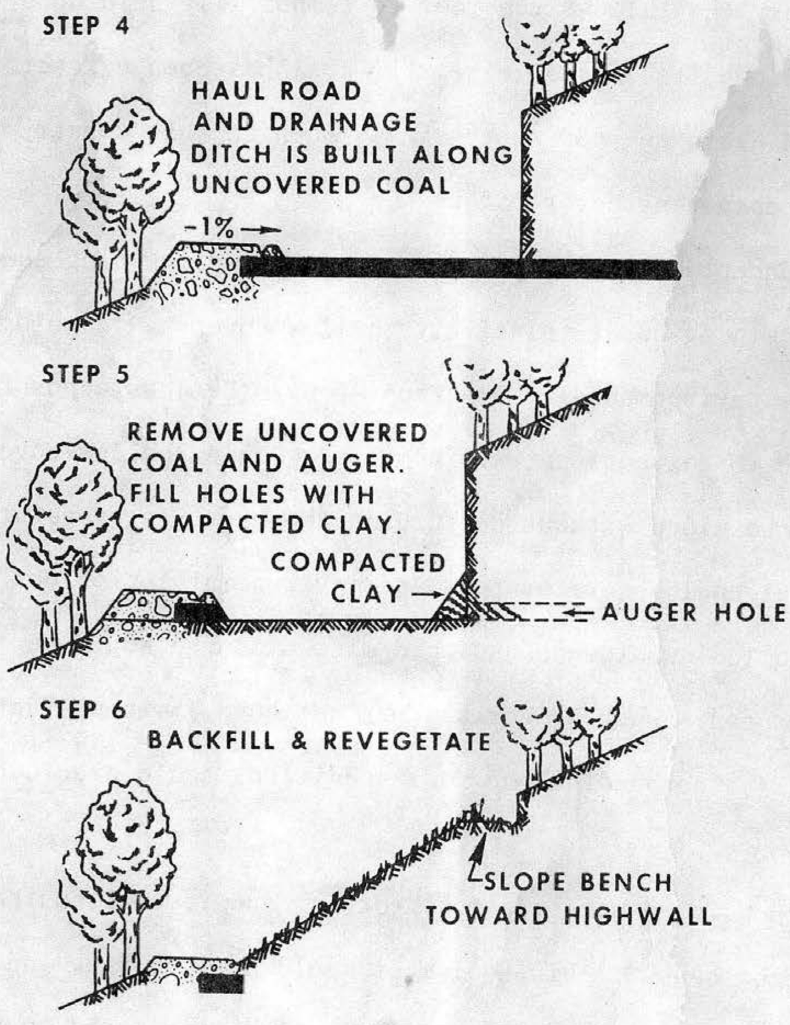


Figure 5.23. Block-cut method:
Controlled placement of spoil, steps 4, 5, and 6.

At the present time, highwall mining using continuous miners is not considered feasible. However, technology has been developed that warrants further research, and chances for success are good.

Longwall mining method [4]--Longwall mining is a method of coal recovery that allows the roof to temporarily held up by jacks and then allowed to subside after the coal has been extracted. This method has been used successfully both in this country and abroad where deep competent cover exists.

The concept of applying underground longwall mining equipment to surface mining under relatively shallow cover was developed by the U.S. Environmental Protection Agency (EPA) as a possible alternative to conventional strip mining. This shallow-covered coal could be mined without disturbing the overlying vegetation, all the coal could be recovered, and environmental problems such as uncontrolled subsidence and acid mine drainage would be greatly reduced. Whereas terrain may not be a limiting factor (Figure 5.24); unconsolidated roof conditions could preclude longwall mining.

The idea is to work the coal cutting and removal equipment from a narrow bench. This equipment would operate back and forth along a wide coal face accompanied by self-moving jacks to prevent the overburden that subsides behind the operation from binding the cutting machine.

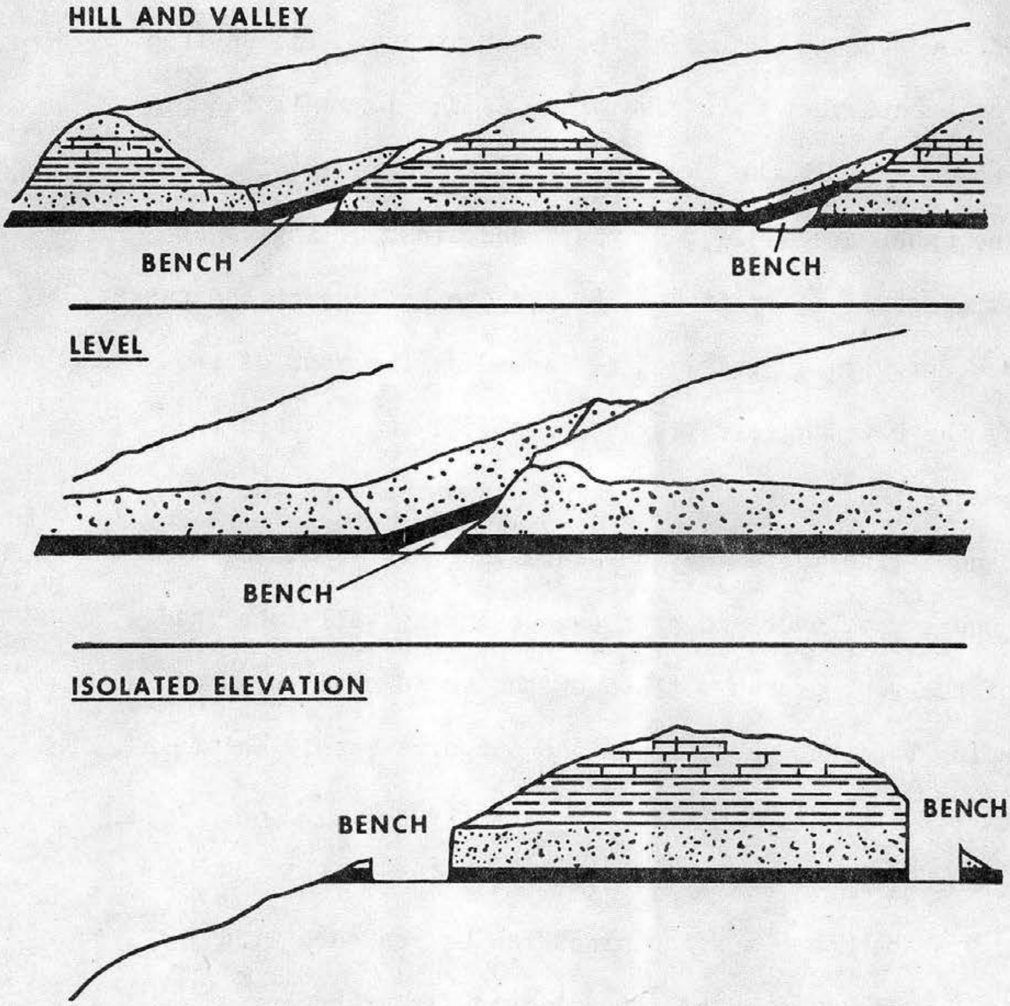


Figure 5.24. Various types of terrain applicable to the longwall stripping system.

The theory of strata control for longwall stripping should be similar to that employed in conventional longwall mining underground. That is, the immediate roof strata above the coal must be supported and allowed to cave in a manner tha allows controlled support and caving of the upper strata. The desired sequence of events that will take place as the longwall face advances would be: 1) the immediate roof is relieved of the load of the upper overburden; 2) the immediate roof sags away from the stronger, higher strata; 3) the chocks advance and cause caving to occur with a breaker line formed at the rear of the chocks; 4) the caved material expands to fill the void in the mined area and the upper roof, forming a span between the gob material and a line where the immediate roof has separated from the upper roof over and near the advancing wall face; and 5) most of the roof pressure taken by the solid coal ahead of the advancing face and the gob and the supports merely maintain the relatively light load of the immediate roof.

Potential advantages of longwall mining are:

1. Abandoned surface mines can be reopened with little or no additional land disturbance.
2. Coal that might not otherwise be mined will be recovered.
3. Longwall mining will work well with other surface mining methods.
4. Total resource recovery is possible.
5. The need to overturn the entire earth surface to recover the coal is eliminated.

Potential advantages of longwall mining: (continued)

6. Landslides are eliminated.
7. Sediment and erosion problems are substantially reduced.
8. Filling the voids left by removing the coal will reduce acid mine drainage, a major problem of underground mining.
9. Subsidence can be controlled.

Potential disadvantages of longwall mining are:

1. Mining method is not perfected.
2. Expensive modification to existing equipment or development of new equipment may be necessary.
3. Small operators will probably not be able to afford the cost of longwall mining equipment.
4. Subsidence could disrupt numerous acquifers and alter underground water patterns.
5. Subsidence could allow air to contact near surface coal seams creating spontaneous combustion problems. This is especially true in the lignite and sub-bituminous coal regions.
6. A soft roof or bottom or a too-strong top that will not cave properly could preclude longwall mining.
7. Outby control of the highwall necessary to prevent slides.

5.2.0. Erosion and Sedimentation Control: Principles and Planning

Sedimentation involves the process by which mineral or organic matter is detached, transported and deposited by moving water, wind or ice. The detachment process is erosion, and the detached particles being transported and deposited are considered sediment.

Erosion and sediment are expensive problems. It is estimated that each year over one-half billion cubic yards of sediment are dredged from waterways. The U.S. Department of Agriculture reports [5] the total cost of such sediment damage and dredging to be approximately 500 million dollars. In addition, it costs approximately 16 million dollars each year just to remove sediment from irrigation ditches.

Soil erosion, the displacement of soil by the force of moving water, wind, or gravity, accounts for the greatest bulk of suspended materials in the nation's waters. In addition to the fact that most sediment is derived from eroded soil, such erosion is a serious and costly problem in itself. Soil erosion has been referred to as a silent thief which robs topsoil from farms, leaves gaping scars in landscapes, undermines houses, road and bridges, and contributes to flooding. Soil erosion and sediment are twin problems, linked by the pull of gravity. It is not possible to separate the problem of sediment damage from the problem of soil erosion. Damage is inflicted at the scene where soil is eroded, where it is washed downstream and where sediment remains suspended or comes to rest.

Efforts to control soil erosion should focus on three broad categories of land disturbance. A significant proportion of soil erosion is of the "natural" or geological type. Natural erosion occurs as the result of interaction among the various elements of the environment. Land untouched by man is susceptible to erosion caused by wind, precipitation and moving water. Agricultural, forestry and mining activities produce another type of erosion. In the United States, an estimated three billion tons of soil are washed from cultivated and overgrazed ranges each year [6]. Sediment yields from agricultural lands in watersheds along the lower Mississippi, for example, average about ten tons per acre per year. In the Southeast, sediment yields average about seven tons per acre per year. It is suggested by some sources that about one ton per acre per year is an acceptable sediment yield rate from croplands [7].

A third cause of soil erosion is associated with suburban development. At the present time, more than 4,000 acres of agricultural land are being converted to other uses daily, such as houses, road and highways, schools, businesses, industries, and other improvements. Development on such a massive scale requires extensive disturbance of land involving the movement of millions of tons of topsoil and vegetation. As a consequence of such development, natural watershed drainage patterns are often disrupted without providing appropriate compensation. A report published in 1963 by the Interstate Commission on the Potomac River Basin [8] estimated that sediment from urban developments in the Potomac Basin ran as high as 50 times that yielded from agricultural lands.

Sediment has many harmful effects on water which serve both to impair water quality and to reduce the quantity of available water supplies. By interfering with the penetration of sunlight, some types of sediment particles reduce the capacity of water organisms to absorb waste materials. As a result, the ability of water to purify itself is impaired. The oxygen content of water is also reduced by sediment particles, which endangers the survival of aquatic life such as fish and plants. In several areas of the country, excessive silt has covered the spawning beds of fish, causing a decline in water-based industries.

Sediment also threatens public health and safety by carrying radio-active substances, nitrates, pesticides, and other toxic materials into public water supplies. In addition, harmful bacteria often cling to, or are absorbed by, sediment particles which pose health dangers to water users. Excessive sedimentation produces stagnant streams,lakes and ponds which may endanger community health. In the Southeast, for example, many years of effort to control mosquito breeding have been lost because sediment has filled drainage channels [9]. Public safety is frequently endangered due to the many floods occurring each year because sediment has choked flood prevention reservoirs, leaving little space for storm waters.

Excessive sediment also interferes with water treatment operations. In many urban areas having combined storm and sanitary sewer systems, increased runoff from rainstorms often overburdens treatment facilities, and, consequently, untreated sewage is carried past treatment plants into rivers. In many such areas, increased runoff caused by suburban growth has made storm water and sewer systems completely inadequate. This problem is far more extensive than is generally realized. In terms of volume, sediment ranks above sewage, industrial wastes, and chemical pollution combined [9].

The cost of water treatment increases when sediment interferes with water supplies. The annual cost of removing excess turbidity from public water supplies is estimated to be 14 million dollars [7].

One of the more serious effects of sediment is that it causes a considerable amount of water to be displaced in the nation's water supply reservoirs. The cost of storage space lost to sediment is high--about 50 million dollars annually. More importantly, about 850,000 acre feet storage space is lost at a time when the need for potable water supplies is expected to double within 30 years [9].

Many of the technical means by which erosion and sediment can be controlled are available. When soil erosion cannot be completely controlled, the application of technical measures has shown that erosion can be decreased by a significant amount. Current research and experimentation suggests that many of the same techniques used successfully to control erosion in agricultural areas, can be applied for other purposes as well, including land disturbed by strip mining. The remaining portion of this chapter will present a detailed treatment of current knowledge on erosion and sediment control technology, emphasizing the measures that have immediate applicability in strip mining erosion and sediment control.

5.2.1. The Erosion and Sedimentation Process

The erosion process includes both the detachment and transport of soil particles. The force of raindrops falling on bare soil detaches soil particles. Water running along the ground surface picks up these particles and carries them along as it flows. As runoff gains in velocity and concentration, it detaches more soil particles, cuts rills and gullies into the soil surface and adds to its sediment load.

Four types of erosion caused by falling and flowing water can be recognized [10] (Figure 5.25):

1. Raindrop Erosion: Erosion resulting from the direct impact of falling drops of rain on soil particles. This impact dislodges soil particles and splashes them into the air. The dislodged soil particles can then be easily transported by the flow of surface runoff.

2. Sheet Erosion: The removal of a layer of exposed surface soil by the action of raindrop splash and runoff. The water moves in broad sheets over the land and is not confined in small depressions.

3. Rill and Gully Erosion: As runoff flows, it concentrates in rivulets, cutting several inches deep into the soil surface. These groves are called rills. Gullies may develop in unrepaired rills or in other areas where a concentrated flow of wate r moves over the soil.

4. Stream and Channel Erosion: Increases in the volume and velocity of runoff may cause erosion of the stream or channel banks and bottom.

Sedimentation is the settling out of the soil particles which are transported by water. Sedimentation occurs when the velocity of water in which soil particles are suspended is slowed to a sufficient degree, and for a sufficient period of time, to allow the aprticles to settle out of suspension. Heavier particles, such as sand and gravel, settle out more rapidly than do fine particles such as clay and silt.

The inherent erosion potential of any area is determined by four principal factors: the characteristics of its soil, its vegetative cover, its topography, and its climate. Each of these factors is briefly discussed in the following pages. Although treated separately, it should be noted that they are interrelated in determining erosion potential.

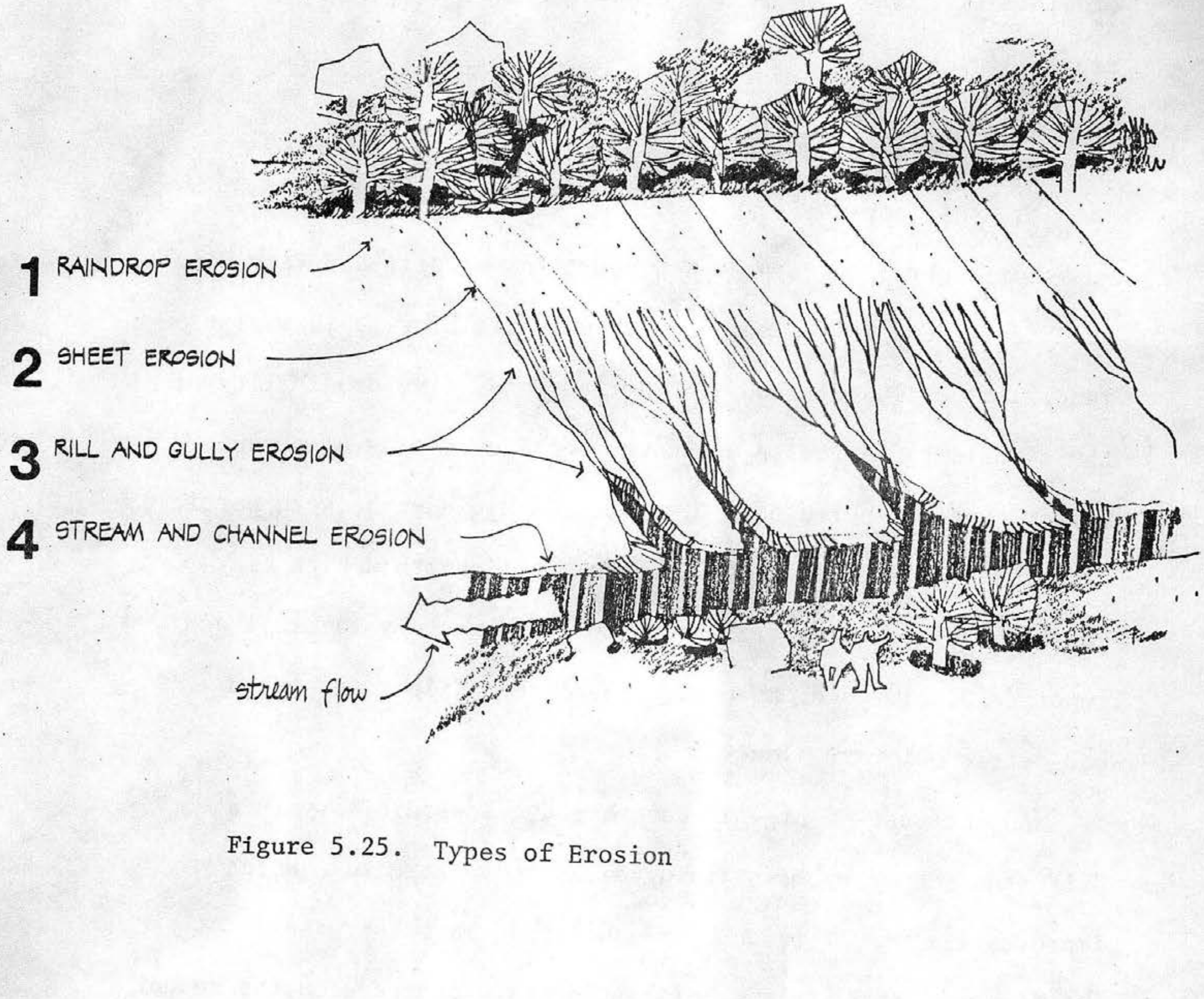


Figure 5.25. Types of Erosion

<u>Soil Characteristics</u>: Soil properties which influence erosion by rainfall and runoff are those factors which affect the infiltration capacity of a soil and those which affect the resistance of the soil to detachment and being carried away by falling or flowing water. The vulnerability of a soil to erosion is known as its erodibility. Some important or key factors which control erodibility are:

1) average particle size and gradation
2) percentage of organic content
3) soil structure
4) soil permeability

Soils which contain high proportions of silt and very fine sand are generally the most erodible. Particles in this size range are easily detached and carried away. The erodibility of these soils is decreased as the percentage of clay or organic matter content increases. Clay acts as a binder between particles and tends to limit erodibility. Most soils with a high clay content are relatively resistant to detachment by rainfall and runoff. Once eroded, however, clays are easily transported and settle out very slowly.

An increase in organic matter reduces erodibility in a different manner by maintaining a favorable structure which improves its stability and permeability. This increases infiltration capacity and delays the start and reduces the amount of runoff.

Well-drained and well-graded gravels and gravel sand mixtures with little or no silt are the least erodible soils. Coarse, granular soils also have high permeabilities and a good infiltration capacity which either prevents or delays runoff. Clayey soils have a very high water holding capacity relative to sands and gravels, but poor infiltration characteristics. In this respect, they are more vulnerable to erosion because they tend to increase the amount of runoff.

The K factor index is considered to be the best index of soil erodibility. A description of the K factor soil erodibility index is presented on Chapter II.

Vegetative Cover: Vegetative cover plays an extremely important role in controlling erosion in the following four ways.

Vegetation:

1. shields the soil surface from the impact of falling rain
2. slows the velocity of runoff
3. maintains the soil's capacity to absorb water
4. holds soil particles in place

By limiting and staging the removal of existing vegetation, and by decreasing the area and duration of exposure, soil erosion and sedimentation can be significantly reduced.

Topography: The size and shape of a watershed influences the amount and rate of runoff. Several of the erosion control measures which will be described in Section 5.3.0. deal with measures to protect vulnerable areas from high concentrations of runoff. Diversions, as well as a number of other control measures, intercept runoff from higher watershed areas, store or divert it away from vulnerable areas, and direct it toward stabilized outlets.

Slope length and gradient are key elements in determining the volume and velocity of runoff and erosion risks. As both slope length and gradient increase, the rate of runoff increases and the potential for erosion is magnified.

Slopes without vegetation must be protected from runoff and restabilized as rapidly as possible. By limiting the length and gradient of slopes runoff volumes and velocities can be reduced and erosion hazards minimized.

Climate: The frequency, intensity and duration of rainfall are fundamental factors in determining the amounts of runoff produced. As both the volume and the velocity of runoff increase, the capacity of runoff to detach and transport soil particles also increases.

Where storms are frequent, intense, or of long duration, erosion risks are high. Seasonal changes in temperature, as well as variations in rainfall, help to define the high erosion risk period of the year. When precipitation falls as snow, no erosion will take place. In the spring, however, the melting snow adds to the runoff and erosion hazards will be high. Because the ground is still partially frozen, its absorptive capacity is reduced.

On the basis of the foregoing treatment, the following basic principles of erosion and sedimentation control can be postulated:

1. Disturbed areas should be kept as small as practicable.
2. Disturbed areas should be stabilized and protected as soon as possible.
3. Runoff velocities should be kept low.
4. Disturbed areas should be protected from storm water runoff.
5. Sediment should be trapped to keep it from leaving the watershed.

The mining plan must be made to fit the topographic, soil and vegetative characteristics of the area with the minimum disturbance compatible with the operating efficiency and the reclamation requirements. Critically erodible soil, steep slopes, stream banks and drainage patterns should be identified.

The duration of exposure of uncovered land should be kept to a minimum. The mining operation should be such that only the land currently mined is exposed to erosion. All other areas should be protected by any means deemed appropriate.

Two methods are available for stabilizing disturbed areas: structural (mechanical) methods and vegetative methods. In some cases, both of these two ways are combined in order to retard erosion. These control measures are discussed in Section 5.3.0.

The removal of existing vegetative cover and the resulting increase in impermeable surface area during strip mining will increase both the volume and velocity of runoff. These increases must be taken into account when providing for erosion control.

Slope changes should be made to keep slope length and gradient to a minimum. Short slopes and low gradients can keep storm water velocities low, limiting erosion hazards.

Measures can be utilized to prevent water from entering and running over the disturbed area. These protective measures are described in Section 5.3.0.

Sediment can be retained by two methods: filtering runoff as it flows and retaining sediment-laden runoff for a period of time so that the soil particles settle out. Both of these methods are discussed in Section 5.3.0.

5.2.2. Planning for Erosion and Sedimentation Control

An important aspect of modern strip mining is the pre-planning for both the efficient exploitation of the mineral resource and the successful restoration of the land. Mining as an extractive process alone has quickly become obsolete, and the coal mining industry has included land use as a relevant aspect in the planning stage. Moreover, an erosion and sedimentation control strategy can be better implemented when the areas of potential trouble have been recognized at the outset.

The methodology for erosion and sedimentation control in a strip mining operation is outlined as follows:

1. study the topography, soils, drainage patterns, vegetation, and other salient physical features

2. detect potential erosional hazards on the basis of the previous information

3. outline a plan for overburden removal which minimizes the amount of potential erosion

4. design temporary control measures to limit erosion and sedimentaion to a tolerable degree.

The following information is necessary to accomplish the previous steps:

1. a map of the location and an indication of the proximity to lakes, streams and other surface waters

2. a topographic map or slope description of the location, as well as an indication of existing vegetation, predominant land features and a description of existing drainage patterns and facilities

3. a soil survey or written description of soil conditions for the areas which will be exposed during overburden removal.

By analyzing this data, the areas which are most vulnerable to erosion can be located. Overburden removal can then be planned to minimize erosion damages in these areas.

The purpose of the location map is to show the proximity to lakes, streams, or other surface waters whose quality may be affected by the mining operations. The major drainage system within which the site is located should be indicated on the location map.

Proximity to streams and other surface waters can significantly influence the selection of erosion and sedimentation control measures and the ultimate cost of the control program.

Predominant land features that are to be documented in the location map should include:

1. the location and a description of existing vegetative cover

2. the location of existing roads.

The location and description of existing drainage patterns and facilities are also necessary. These should be indicated on the topographic map. The points at which runoff and/or surface water enters and leaves the site should be indicated, as well as the overall direction of surface water movement. The location of all natural or constructed drainage channels and/or enclosed drainage systems should also be indicated.

Soil Characteristics: Published soil surveys are available at Soil Conservation District Offices and at local enforcing agencies. In areas where soil surveys are completed but not yet published and in areas where soil surveys are still in progress, soil survey information is available at the Soil Conservation District Office. A soil survey includes a set of maps on which the location and extent of different soil types are outlined and identified by symbols. The soil survey report also includes a legend which identifies each symbol and describes each type of soil on the map. Each soil series and mapping unit is described in terms of its most important physical and chemical properties. Interpretations are made on the suitability of the different soil series and mapping units for various uses.

Of particular interest in soil erosion and sedimentation control planning are the properties that affect the erodibility of the soil. A chart listing the erodibility ratings of each soil type is available from the Soil Conservation District Office. By using a soil survey, it is relatively simple to identify the different soils present on a particular site and check their erodibility ratings.

Four principal soil properties determine erodibility: 1) particle size and gradation,2) percentage of organic content, 3) soil structure,4) soil permeability.

These soil characteristics can be measured in a series of laboratory tests and their values used in an erodibility equation which yields the erodibility index of the soil K. This is one of the five factors that make up the Universal Soil Loss Equation. This equation is used to estimate the amount of soil that will be lost from a site in tons per acre per year. The higher K factor index the more erodible is the soil. The following values can be used as a general indication of potential erodibility.

.23 and lower	low erodibility
.24 - .36	moderate erodibility
.37 and higher	high erodibility

The process of making specific conclusions about critically erodible areas involves the interpretation of the information on topography and soils. In general, critical areas have one of the following conditions: 1) highly erodible soil, 2) high erosion hazard slope, 3) moderately erodible soil and moderate erosion hazard slope.

A complete analysis involves the determination of the critical areas, and an evaluation of the surrounding environment. The following steps should be included in the analysis:

1. Indicate where soils, topography and/or vegetation combine to create critically erodible areas.

2. Indicate how the mining site relates to surrounding streams, drainageways, or other bodies of water. Assess the vulnerability to erosion and sediment damage of these drainageways and surface waters and all off-site areas.

3. Indicate where storm water runoff crosses the mining site. Indicate the potential options for disposing of storm water runoff by including potential locations of sediment control structures.

4. Indicate how disturbed areas might be protected from increasing surface storm water runoff.

The plan for overburden removal should minimize the disturbance of critical areas, as documented by the foregoing analysis. Sites with large areas of steep slopes (over 16%) or highly erodible overburden are improperly suited for mining from the point of view of erosion and sediment control. However, careful planning to avoid extensive mining during the rainy season can result in increased efficiency in the exploitation of the resource as well as in the strategy of erosion control.

Drainage Patterns: Providing for good drainage is also a part of the erosion and sediment control planning strategy. Three common methods for providing site drainage are:

1. the surface drainage system
2. the enclosed underground drainage system
3. the enclosed underground drainage system with on-site storage

In the surface drainage system, the runoff is collected and conveyed off the site in surface drainage channels. The channel must be designed so that channel erosion does not occur. The surface roughness of the vegetative channel lining slows runoff velocity. This reduction of velocity is desirable; however, under certain conditions surface channels must be paved to prevent erosion within the channel. The outlets of paved surface channels must control the runoff and sediment load at discharge sites. Where structural lining is necessary in a small percentage of the total surface of the drainage system, cost advantages will make the use of a surface drainage system a preferred alternative.

Surface drainage systems can release runoff to off-site surface drainageways or streams, or to an on-site sediment basin. In some cases, an on-site retention basin will be necessary to control the velocity of runoff released from the site. The principal disadvantage of the surface drainage system is its potential for on-site erosion. Such erosion will occur if channels are not adequately designed, stabilized and maintained.

An enclosed underground drainage system intercepts runoff and conveys it to an outlet at the edge of the site (surface drainageway or stream), or to an on-site sedimentation and storage basin. The major advantage of the enclosed drainage system is that the increased volume and velocity of runoff can be intercepted before runoff can cause on-site erosion damage. The principal disadvantage of the enclosed drainage system is that the velocity of runoff is increased and sediment is not often filtered from runoff. As a result, the points at which runoff is released from the system will be subject to erosion and sedimentation. Thus, while the potential for erosion damage to the site itself is minimized, the erosion and sedimentation damage to offsite areas may be increased.

The enclosed underground drainage with on-site storage has the advantages of the enclosed drainage system of on-site erosion control, and yet it avoids off-site damage. Instead of merely delaying the erosion and sedimentation impact of the enclosed drainage system, the on-site, storage-controlled runoff release system largely eliminates this impact.

Three major factors are involved in determining which drainage system is the best alternative for a particular mining site:

1) the slope and soil conditions
2) the intensity and scale of the mining operations
3) the existing off-site drainage facilities.

Extreme slopes and highly erodible soils can make an unlined surface drainage system impractical for erosion control. Where surface drainage channels can be expected to erode because of slope or soil conditions, the use of an enclosed drainage system may be a better alternative. However, the outlet of the enclosed system must be properly stabilized.

The drainage system is closely related to the intensity and scale of the mining operation. In extensive mining operations, it is possible that an unlined surface drainage system alone will not convey the runoff volume generated. An enclosed drainage system may provide a better choice when handling large volumes of runoff.

Where a sediment basin is contemplated, its size is determined by the erosion rate and the amount of runoff generated in the mining site. The basin must be located at or near the low point of the site. A sediment basin that will be retained as a pond after the mining must be designed to function properly for the intended land use.

The existing off-site drainage facilities have a definite bearing on the selection of the on-site drainage system. Local regulations may dictate the characteristics of the on-site drainage to avoid upsetting the off-site drainage system.

There are two steps in planning for erosion and sedimentation control. The first involves an investigation and analysis of the site characteristics which determine probable critically erodible areas. The second step is to develop a strategy for implementing a combination of erosion and sedimentation control measures. The following documents should be prepared to insure an effective strategy:

1. site location map
2. topographic survey
3. soil survey
4. site analysis to determine critically erodible areas
5. plan for overburden removal on the basis of the foregoing analysis
6. erosion control plan specifying the control measures proposed.

5.3.0. Erosion and Sedimentation Control Measures

This section deals with the various measures that can be used in the implementation of the strategy for erosion and sedimentation control. Erosion control measures serve to divert runoff from vulnerable areas, safely convey runoff or provide for adequate drainage. Sedimentation control measures serve to filter runoff as it flows or detain it for a period of time sufficient to allow for the settlement of the sediment particles.

Erosion and sedimentation control measures can be classified according to their nature as either vegetative or mechanical. Vegetative measures include the planting of grasses and other vegetation to stabilize inadequately protected soils surfaces. Mechanical measures include control techniques which involve the building of structures (check dams, sediment basins, diversions, etc.), paving, or the operation of equipment to achieve compaction or surface roughening.

Vegetative and mechanical erosion and sedimentation control measures can be classified as either temporary or permanent depending on whether or not they will remain in use after mining has been completed. Annual grasses, mulches and netting, for example, are temporary control measures although they may reamin in place after mining has been completed. The planting of perennial grasses, sod, shrubs and trees are permanent vegetative control measures.

Extensive surface mining in areas of high erosion potential may require the construction of permanent measures, installed at the beginning of mining, which will be in operation long after mining has been completed. Where limited amounts of erosion and sedimentation would do significant damage, measures to control runoff and trap sediment will be necessary.

Temporary measures are designed to be used during and immediately after mining. In some cases, temporary measures can be planned so that they can be converted to permanent after mining. For example, sediment basins can be converted to permanent ponds which can be used for recreational purposes.

The erosion and sedimentation control measures can be classified according to the specific problem areas that follow:

1) Slopes
2) Streams and Waterways
3) Surface Drainage
4) Overland Flow

5.3.1. Slope Control Measures

Runoff velocity increases as slope length and gradient increase. As the velocity increases, so does its capacity to detach and transport soil particles. In general, the flatter and shorter a slope, the slower the runoff velocity and the greater the infiltration rate. The removal of existing vegetative cover from slopes increases the vulnerability of the slopes to erosion. Vegetation retards runoff velocity and root systems hold soil particles in place. Vegetation maintains the capacity of the soil to absorb precipitation.

Erosion problems in slopes originate when one or more of the following conditions are present:

1) Slope length is extensive
2) Slope gradient is steep
3) Slope soil erodibility is high

The erosion and sedimentation control measures which are commonly used to minimize the potential erosion originating in the aforementioned condition are described in the following pages.

Diversion Measures: A diversion consists of a channel constructed across a sloping surface to intercept runoff before it attains sufficient volume and velocity to be a potential erosion hazard. Its design capacity should be able to carry storm runoff and its surface should be able to sustain the erosive force of the running water. Flow from a diversion must be discharged into a protected area or a grassed waterway.

A diversion can consist of a dike, a ditch, or a combination of both. A diversion is used along vulnerable areas exposed during mining. Temporary diversions must remain in place until the protected slopes have been permanently stabilized.

The design of the diversion is based on the following:

1) Storm runoff to be intercepted. This sets the design discharge.

2) The runoff velocity and soil erodibility in the diversion, that determine the type of protective cover to ensure an adequate design against the erosive forces in the channel.

When properly constructed and maintained, diversions are effective devices for minimizing the runoff over unprotected slopes and other areas of high erosion potential. Diversions are also used to collect runoff from a site and convey it to a sediment retention basin.

The following are two common diversion measures quoted from reference [11].

1) Diversion dikes.

A diversion dike is a temporary ridge of soil constructed at the top of cut or fill slopes. They divert overland flow from small areas away from unprotected slopes. They are used as a temporary measure at the top of a new slope.

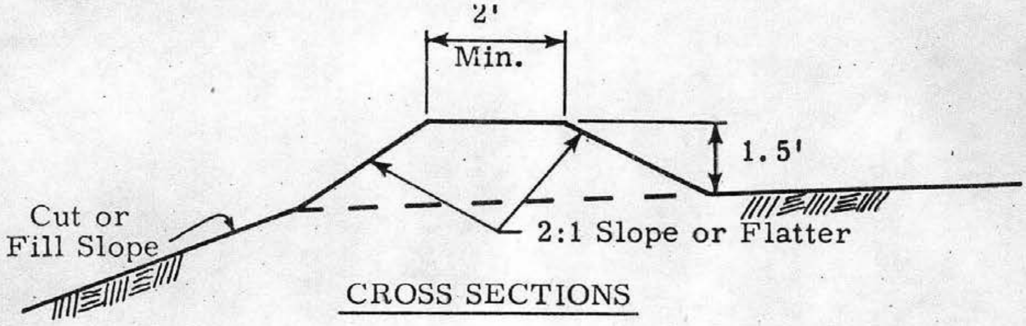
The following are general criteria:

Height:	1-5 feet
Top Width:	2 feet
Side Slopes:	2:1 or flatter
Compaction:	85% Proctor Standard Density
Grade:	Positive. Excessive grades may require additional stabilization measures in the flow area.
Maintenance:	Inspection required after each storm to locate and repair any damaged areas.

2) Interceptor Dikes.

An interceptor dike is a temporary ridge of soil constructed across a graded slope. The spacing between interceptor dikes should be about 250 feet, but very steep slopes may require closer spacing.

General design criteria is the same as for diversion dikes.



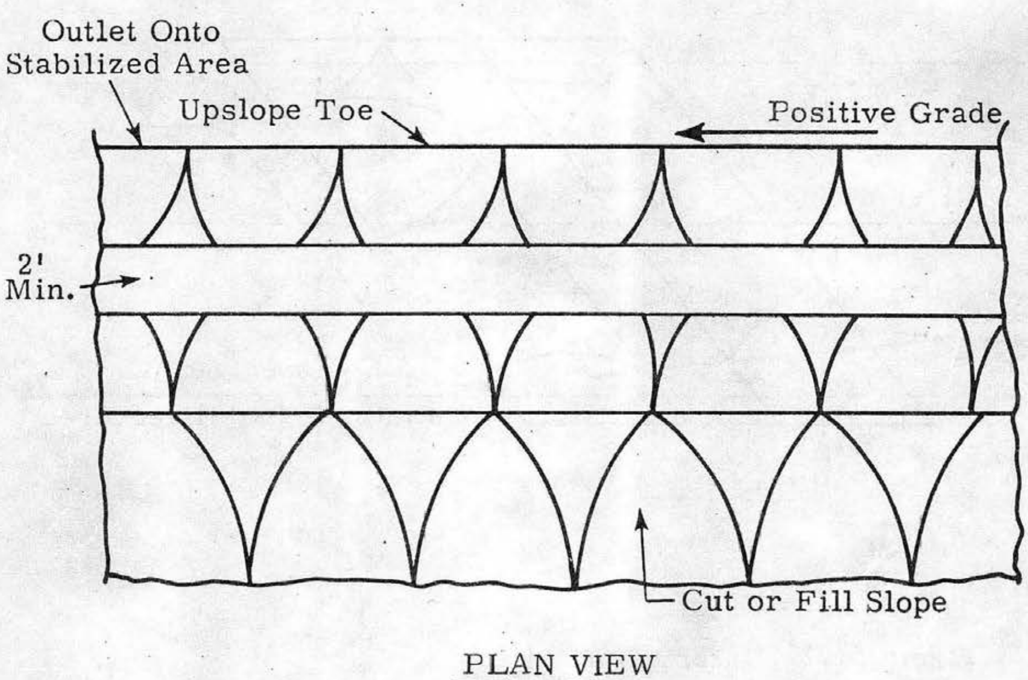


Figure 5.26. Diversion Dikes

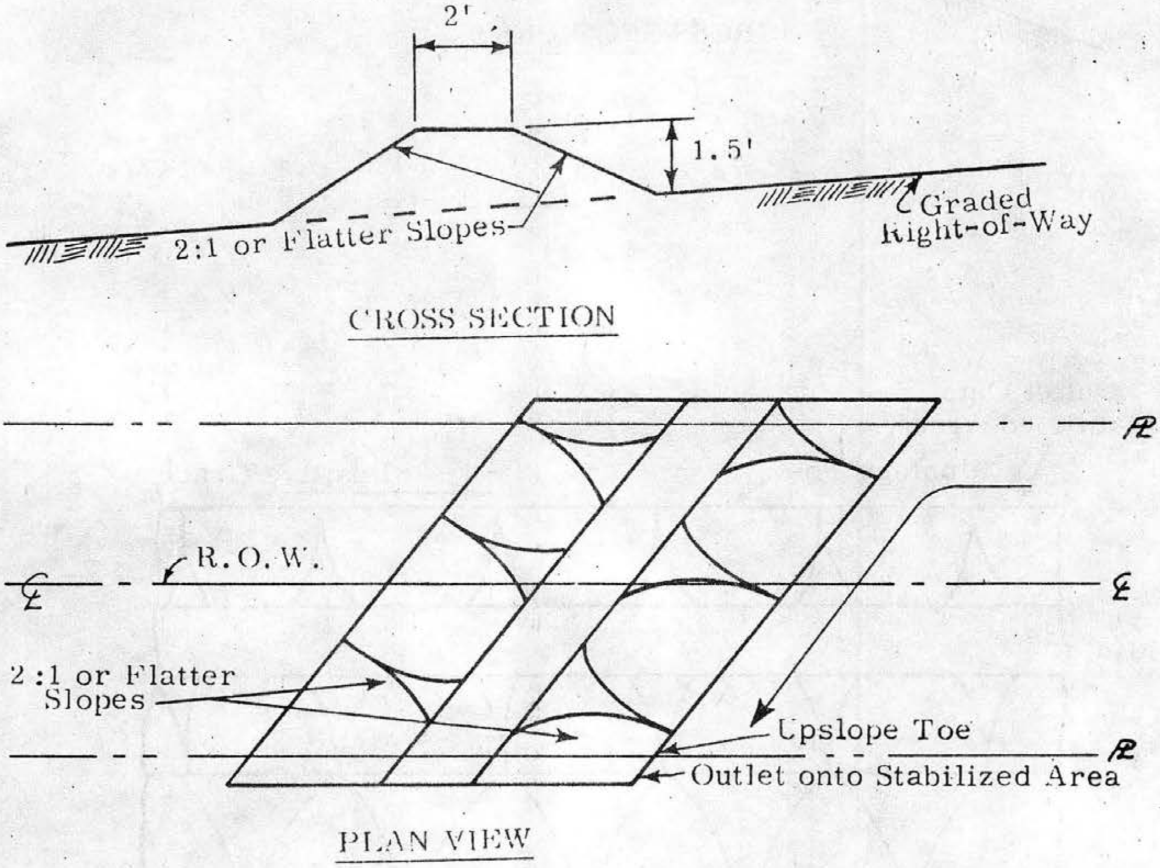


Figure 5.27. Interceptor Dike

Slope Drains: Where runoff cannot be satisfactorily disposed of by conveying it laterally, it can be drained over the face of the slope itself. Slope drains can run down the surface of the slope as a sectional downdrain, paved chute or a pipe placed beneath the surface of the slope.

On-surface sectional downdrains are usually pipes made of corrugated metal, bituminous fiber, or other material; these slope drains are temporary. Paved chutes are covered with a surface of concrete or bituminous material and these chutes are usually permanent as are subsurface pipes.

Undercutting at the lip of the slope drain and piping under the drain frequently occur. This can be prevented by compacting the soil carefully at the mouth of the slope drain and anchoring it adequately.

At the slope drain outlet, energy dissipators are frequently necessary. Failure to utilize an energy dissipator can result in serious erosion problems at the outflow end of the slope drain. The purpose of the energy dissipator is to slow the velocity of the storm water runoff to a level that is nonerosive. Riprap is an effective energy dissipator.

The following are three common slope drain measures [11]:

1) Sectional Downdrain

   A sectional downdrain is a prefabricated, sectional conduit of half-round or third-round, bituminized fiber pipe or other material. A sectional downdrain conducts storm runoff from one elevation to another without erosion. They are used as a temporary or permanent structure on slopes where concentrated runoff would cause excessive slope erosion. The design diameter should be sufficient to carry the storm flow, and placement should be on undistrubed soil or compacted fill. Outlet should be to a stabilized area. Periodical inspection for damage is required.

2) Chutes and Flumes

Chutes and flumes are steep channels of concrete of comparable material. They are designed to conduct storm runoff from one elevation to another without erosion of the slope. They are used as temporary or permanent structures down slopes where concentrated runoff would cause soil erosion.

Design Criteria:
Formal design guidance is usually required to properly size the proposed structure. Placement should be on undisturbed soil or well-compacted fill. The slope should be between 1.5:1 and 20:1. Some form of energy dissipating device should be incorporated into the outlet structure at the toe of the slope.

3) Flexible Downdrain

A flexible downdrain is a flexible conduit of heavy duty fabric or similar material. Its purpose is to conduct storm runoff from one elevation to another without erosion of the slope. They are used as temporary structures down slopes where concentrated runoff would cause excessive slope erosion.

Design Criteria:
Formal design is not required. Placement should be on undisturbed soil or well-compacted fill. The end sections should be of standard metal, and entrance section should slope toward outlet at a rate of at least ½-inch per foot. Soil should be carefully placed and compacted around entrance section. Extension collars should be 12 inches long, corrugated metal pipe. Anchoring is done by metal T pins through grommets attached to the flexible downdrain, at 20 foot centers. Outlet should be to a stabilized area wherever possible. Inspection for clogging and damage after each storm is required.

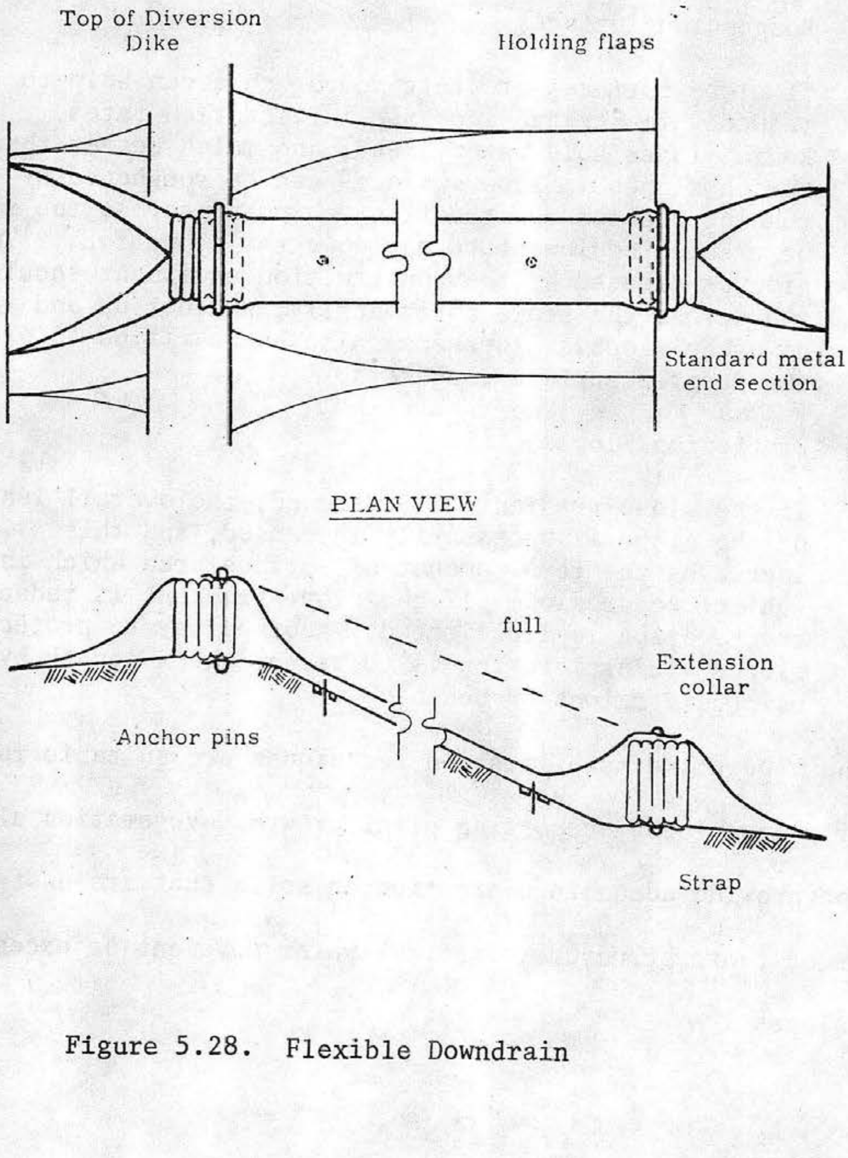


Figure 5.28. Flexible Downdrain

Slope Stabilization: The stabilization of slopes is carried out by the following two ways:

1) mechanical stabilization
2) vegetative stabilization

The following are commonly used mechanical stabilization techniques to minimize erosion in slopes.

1) Roughening Surfaces

   If slope surfaces are left rough, this can help to reduce velocity and increase infiltration rates. Rough slopes hold water, seed, and mulch better than smooth slopes. Slope surfaces can be roughened by running wheeled construction equipment across the slope, or tracked equipment up and down the slope face. The grooves created by the construction equipment should run across the slope horizontally, and not up and down the slope. Slopes can also be scarified to produce the desired surface roughness.

2) Flattening Slopes

   If the slope gradient is flattened, the overall length of the slope is necessarily increased, and this increases the total amount of surface area which is subject to erosion. If the slope gradient is reduced, revegetation is facilitated. Another way to protect slopes against erosion is to reduce their length by using diversions or benches.

The vegetative stabilization techniques are suitable for all soils capable of supporting plant growth. Vegetation alone will not provide adequate protection on soils that are unstable because of their structure, internal water movement or excessive steep slopes.

Vegetation is usually established in one of the following three ways:

1) Hydro-seeding: A mixture of seeds, fertilizer, and water is sprayed on the slope. A mulch and a mulch tacking agent can also be applied. This method is effective on large areas.

2) Standard seeding: Seed is drilled or broadcast either mechanically or by hand. A cultipacker or similar tool is used after seeding to make the seed-bed firm and to provide seed covering. The proper timing of seeding, mulching, and watering is important for areas seeded in this manner.

3) Sodding: Sod strips are laid on the slope and in this way instant cover is provided. Sod should be placed on a prepared bed and pegged on steep slopes. Watering is important. This method is effective and is often used on steep slopes.

A suitable soil, good seedbed preparation, and adequate lime and fertilizer are required for all of these methods.

Immediately after rough grading is completed, exposed slope should be temporarily stabilized if final grading will be delayed. Temporary seeding and mulching may be used or temporary mulching alone may be used for short periods of protection.

As soon as slopes are brought up to final grade, permanent vegetative stabilization measures should be initiated. The selection of the appropriate plant materials for permanent stabilization should be based on a consideration of the following factors:

1) soil and climate conditions
2) duration, quantity, and velocity of runoff
3) time required to establish cover
4) maintenance requirements
5) site use

Grass is the least expensive and most effective material for permanent protection of eroding soils. It can be successfully established if the following requirements are met:

1) proper seeding mixture is selected for the site
2) seeding dates are observed
3) area to be seeded is covered with topsoil
4) proper seedbed preparation and planting methods are used
5) adequate fertilizer is applied
6) protection from wind and water erosion is provided during establishment.

Mulch is used after permanent seeding as well as before seeding to protect exposed areas for short periods. Mulches protect the soil from the impact of falling rain. They slow the velocity of runoff and increase the capacity of the soil to absorb water. Mulches hold seeds in place, preserve soil moisture, and insulate germinating seeds from the extremes of heat and cold. Many types of mulch are available: straw, woodchips, and excelsior mats are commonly used among others. Most mulches must be anchored. Asphalt emulsions can be used, as well as netting made of jute, fiberglass, or plastic.

Sediment can also be reduced by maintaining a natural vegetative buffer or filter strip at the base of a slope and also by placing sod strips at intervals along the face of the slope. These measures may help to slow runoff, trap sediment, and reduce the volume of runoff on slopes.

Slope gradient is an important factor in the success of vegetative restabilization measures. On steep slopes (2:1 or steeper) normal tillage equipment cannot be used to prepare a seedbed. Storm water runoff will result in the loss of seeds, fertilizer, and soil. Sod can be used to stabilize steep slopes instead of seeding where grades are not more than 2:1. Sod on slopes of this type should be pegged.

Steeply sloped areas such as lakeshores and road banks involve three special considerations:

1. To insure probability of successful stabilization, banks should consist of slopes that are 2:1 or flatter.

2. The toe of the slope must be protected from undercutting or other erosive forces by mechanical means where necessary.

3. Water seepage coming out on the face of the slope should be intercepted by a properly designed drainage system.

5.3.2 Streams and Waterways Control Measures

The protection of streams and waterways near the mining site against the detrimental effects of erosion and sedimentation involves the following aspects:

1) Stream banks must be protected against the erosive velocities caused by increased runoff.

2) The rate of release of increased runoff into the waterway must be controlled.

3) Excessive sediment loads from mining areas must not be allowed to enter streams.

Streams that are particularly vulnerable to erosion should be identified at the outset of the mining operation. Streams which have a small channel capacity and steep banks are very susceptible to erosion. Streams which flow through areas of erodible soil and streams with sharp meanders or bends in the channel alignment are also prone to erosion.

<u>Bank Stabilization</u>: Streams and waterways are stabilized by resorting to any one of various methods of bank stabilization. These methods can be vegetative or mechanical in nature.

Vegetative stabilization must be initiated after grading on stream banks has been completed. Grass and legume vegetation is recommended for the protection of stream banks.

As soon as planting or seeding has been completed, banks should be mulched and the mulch securely anchored. Other stabilization measures may include netting placed over straw. Periodic inspection and the repair of areas where vegetation has failed is important for erosion control on stream banks.

Mechanical stabilization is accomplished through a variety of methods which either create a barrier that will withstand the erosive forces exerted by the flowing water or create a bank roughness that will reduce the erosive power of the water as it moves along the bank. Methods commonly used include revetments and deflectors. Revetments, which cover the banks, are commonly used in sharp bends or constrictions. Riprap, gabions, sacked concrete, and concrete or asphalt paving are used as revetment materials. Deflectors consist of jetties or pilings that angle outward from the bank in a downstream direction and deflect currents away from vulnerable bank areas.

Design criteria on 1) gabions, and 2) erosion control mats follows.

1) Gabions

Gabions are large, multi-celled, rectangular wire mesh boxes. They form flexible monolithic building blocks used for construction of erosion control structures. They are used in channels, revetments, retaining walls, abutments, check dams, etc. Design should be made by competent professionals. Construction design should ensure that foundations are properly prepared to receive gabions, that the gabion structure is secured to the foundation, and that the rock used is durable and of adequate size. Periodic inspection is necessary to avert signs of undercutting or excessive erosion at transition areas.

2) Erosion Control Mats

Erosion control mats are marketed under the tradename Fabriform (R)*. The Fabriform (R)* process is a technique for pressure injecting fluid mortar into flexible fabric forms. It provides structure, slope and grade protection, above and below water. They are used in channel lining, revetments and check dams.

Filter point mats are designed to relieve hydrostatic uplift pressures. They also tend to articulate along the lines of the filter points to minimize undercutting. Flow-alteration characteristics of the cobble-like surface of filter point mats make them effective in slowing water velocity in fast streams and at outfall installations. Uniform cross-section mats are recommended for installation where the primary objective is impermeability and low hydraulic friction. Periodic inspection is necessary to avert signs of undercutting or excessive erosion at transition areas.

Grade Control Structures: Grade control structures can be used to reduce the velocity of flow in a channel. Check dams, weirs, and drop spillways, made of a variety of materials, both temporary and permanent, reduce channel grade and dissipate the energy of flowing water.

Special care must be taken in the planning, engineering, and construction of such structures to prevent undercutting at the

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*(R) Trademark

toe of the structure and erosion of the banks. Grade control structures concentrate the volume of water flow and increase its velocity at the structure and, therefore banks around grade control structures often require additional stabilization measures.

Check dams are structures used to stabilize the grade or to control head cutting in natural or artificial channels. They are used to reduce or prevent excessive erosion by reduction of velocities in watercourses or by providing partial lined channel sections or structures that can withstand high flow velocities.

Check dams are used where the capability of earth or vegetative measures is exceeded in the safe handling of water at permissible velocities, where excessive grade or overfall conditions occur, or where water is to be lowered from one elevation to another. Formal design is generally required. Maintenance is generally not required.

Sedimentation Control Measures: The first essential step in preventing sediment from entering streams and waterways is to control erosion at the mining site. A second necessary step in sediment control is to trap sediment that is transported by runoff before it reaches streams and waterways or leaves the mining site.

To trap sediment, the runoff must be detained for a sufficient period of time to allow the suspended soil particles to settle out. The amount of sediment which is deposited will depend on the speed at which runoff flows through the sediment trap, the length of time that runoff is detained, and the size and weight of the soil particles which are in suspension.

Several techniques are available for controlling the amount of sediment which reaches streams and waterways. Vegetative filter strips between streams and mining areas serve to slow runoff and filter out sediment. Sediment traps can also be constructed in drainageways. Sandbags, straw bale barriers, and excavated sediment traps, placed at regular intervals within a drainage channel, are temporary sediment control measures which are easy and economical to construct. Sandbag barrier sediment traps are constructed of bags filled with sand or crushed rock and stacked in an interlocking manner which is designed to trap sediment and reduce the velocity of flow. Straw bale barrier sediment traps are constructed of bales of hay or straw stacked and staked in place. Tying the bales to stakes with wire proviedes additional stability. Soil excavated from the drainage channel should be compacted along the upstream face of the barrier.

Piping, or undercutting, can be reduced by setting the sandbags or straw bales at least 6 inches into the bottom of the drainageway and compacting excavated soil along the upstream side. These sediment traps require cleaning out periodically and they should be checked after each rain to repair any damage to the check dam and remove sediment from the trap basin if necessary.

Streams may also be protected form increased sediment loads by trapping runoff in sediment basins before it is released into stream channels. In addition to trapping sediment, these basins are designed to release runoff at non-erosive rates. Such sediment basins can be constructed by excavating a pit or by construction of an impoundment.

Sediment basins often consist of an earthen dam, mechanical spillway (including a perforated riser pipe), and an emergency spillway. They are generally located at or near the low point of the site. Points of discharge from sediment basins must be stabilized.

Technical information on the following measures for sediment control follows:

1) Sandbag Sediment Barriers [11]

Sandbag sediment barriers are temporary barriers or diversions that are constructed of sandbags. The barriers are used to retain sediment on-site by slowing storm run-off and causing the deposition of sediment at the structure. They are used at storm drain inlets, across minor swales and ditches, and for other applications of temporary nature.

Sandbag sediment barriers should be installed so that flow under or between bags is minimal. Anchoring with steel rods may be required if structure height exceeds two bags. Frequent inspection is necessary to avert damages caused by vandalism. After storm cleaning is required.

2) Straw Bale Sediment Barriers

Straw bale sediment barriers are temporary berms, diversions or other barriers that are constructed of baled straw. They retain sediment on-site by retarding and filtering storm runoff. They are used at storm drain inlets, across minor swales and ditches, as training dikes and berms, along property lines, and for other applications of primarily temporary nature. Bales bound with nylon or wire are more durable than twine bound bales. Bales should be anchored to the ground with steel pins, fence posts, rebars, wood pickets, etc. Two anchors per bale are required. Bales must be installed so that runoff cannot escape freely under the bales. Frequent inspection is necessary to avert damages caused by vandalism. After storm cleaning is required.

3) Sediment Retention Basins

A Sediment Retention Basin is a temporary dam or basin or a combination of both that will trap and store sediment produced on exposed areas and delivered to the structure by storm runoff. Sediment Retention Basins trap and retain sediment generated during construction activities on-site. Sediment Retention Basins are used across channels and drainageways that are on, or adjacent to, construction sit sites.

Formal design is required. Appendix A contains standards and specifications for sediment basins prepared by the Soil Conservation Service for specific use within the State of Maryland [12]. The appendices to the specifications are not included.

5.3.3 Surface Drainage Control Measures

Surface runoff, and runoff intercepted by erosion control measures such as diversions, must be collected by drainageways and let out in stabilized areas, storm sewers, or sediment basins. The design of these drainageways insure that runoff is transported without risk of erosion or flooding. Unless surface drainageways are adequately designed, constructed, and maintained, they can become a major source of sediment pollution.

The mining operation should be planned to maintain and utilize the naturally stabilized drainageways that exist on a site. Increases in runoff volume and velocity because of changes in soil and surface conditions during and after mining must be anticipated. Where the capacity of the natural site drainage channels is exceeded, additional capacity, stabilizing vegetation, and structural measures may be needed. Allowable design velocities vary with soil conditions, the character of the channel lining (either bare, vegetative, or structural), and anticipated runoff volume.

Erosion and sedimentation from surface runoff can be minimized through the use of the following control measures:

1) Grassed Waterways

Grassed waterways are vegetatively stabilized channels. Jute netting, excelsior blankets, and various other mulching techniques are frequently used to protect channels until vegetation becomes well established. The objective is to achieve a dense and uniform vegetative cover. In some vegetatively lined channels, bank protection may also be necessary. Riprap is a commonly used material.

2) Bare Channels

These channels should be used only where low gradients can be implemented or in soils of low erodibility.

3) Lined Channels

Structural linings are necessary in drainageways where vegetation cannot be established because flow is of long duration in the channel, runoff velocities or concentrations are high, erodible soils exist, or slopes are very steep.

The most commonly used channel linings are concrete, asphalt paving, or riprap. In general, vegetative stabilization and the use of permeable channel linings, such as non-grouted riprap, are preferred to the use of impermeable linings, such as concrete.

4) Grade Control Structures

To reduce the velocity of runoff in drainageways, a variety of grade control structures can be used. These structures can be either temporary or permanent depending on the long-range requirements for the site. Pipe drops and drop spillways can be used.

5.3.4 Overland Flow Control Measures

Although erosion rates on steep exposed slopes are higher than on flat or gently sloping areas, all areas of exposed soil are vulnerable to erosion. If erosion control is ignored on large areas of nearly flat or gently sloping land, it will be possible for significant amounts of soil to be eroded. Clearing, grading, and vegetative restabilization in these areas can be timed so that the extent of exposed area and the duration of exposure is minimized. These areas require prompt vegetation restabilization. Temporary seeding or mulching is required where large areas will not be permanently stabilized within recommended time limits. Diversions, sediment barriers, or traps constructed on the lower side of large disturbed areas should be used to intercept and collect sediment.

Gravel or stone filter berms should be used at intervals along the gradient right-of-way to intercept runoff and direct it to stabilized areas, drainageways, or enclosed drainage system inlets. Filter berms also serve to slow and filter runoff and collect sediment. These berms can be crossed by construction equipment.

The amount of erosion on flat and gently sloping surface areas can be significant. Erosion on these areas can be minimized by:

1) Scheduling the mining operation in phases. The extent of the exposed area and the duration of exposure should be kept to the minimum practicable.

2) Vegetative restabilization. Prompt surface stabilization with either temporary or permanent vegetative cover minimizes erosion.

3) Sediment traps. These measures trap soil eroded from exposed surface areas before it is carried off the mining site or into waterways.

Spoil areas present the same problems for the control of erosion and sedimentation as exposed cuts. Runoff should be diverted from the face of the slopes which are exposed in the stripping process. The runoff must then be conveyed in stabilized channels to stable disposal points.

The measures used to control erosion on slopes, such as diversions, slope drains, etc., are applicable in borrow areas. Immediately after the coal has been recovered, the exposed area should be stabilized. The reclamation of the land after the mining operation involves the following phases:

1. grading
2. covering with topsoil
3. seeding with permanent vegetation

If final grading is delayed, temporary seeding should be used. By properly timing the disturbance of the natural cover in the mining area in carefully planned phases, the area of exposed soil and the duration of exposure are reduced and, therefore, erosion losses are reduced.

The topsoil from mining areas should be stripped and stockpiled for later redistribution on the disturbed area. These stockpiles should be located on the uphill side of the excavated area wherever possible so that they can act as diversions. Stockpiles should be shaped and seeded with temporary cover.

After mining is completed, the area should be restored to its approximate original contour. Regrading to insure proper drainage and to blend the borrow area with the surrounding topography is required. Stockpiled topsoil is then redistributed and permanent vegetative cover reestablished.

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APPENDIX

INTERIM STANDARD AND SPECIFICATIONS FOR SEDIMENT BASIN

DEFINITION, PURPOSE, AND CONDITIONS WHERE APPLICABLE:

A sediment basin is created by the construction of a barrier or dam across a drainageway, or by excavating a basin, or by a combination of both, to trap and store sediment from erodible areas in order to protect properties and stream channels below the installation from excessive siltation. This specification applies only to sediment basins that are temporary in nature and will be removed upon completion of the development period.

Sediment basins that are to remain as a water storage facility after the development period will be designed and constructed to conform to Maryland State Law, as found in Article 96A, Maryland Water Resource Law. This practice applies primarily to areas where land grading operations are planned or are underway. It is used as a temporary measure until areas above the installation are permanently protected against erosion by vegetative or mechanical means.

Sediment basins covered by this standard and specification will be limited to the following two categories.

Class "X" - Sediment control basins designed with a dam 10 feet or less in height and with less than one million gallon storage capacity below the pipe spillway crest.

Class "B" - Sediment basins with the following criteria will fall in Class "B": The water surface area at the crest elevation of the pipe spillway shall not exceed nine (9) feet measured upward from the original stream bed to the crest elevation of the pipe spillway; and the drainage area shall not exceed one hundred fifty (150) acres.

NOTE:

This standard and specification shall not apply to sediment basins in which any of the above criteria for Class "B" sediment basins is exceeded.

DESIGN:

Storage - The site should be selected to provide adequate storage for not less than 0.5 inches per acre of drainage area. Volume for trap efficiency calculations shall be the volume below the emergency spillway crest or pipe spillway crest if there is no emergency spillway. When necessary, consideration should be given either to excavating additional storage capacity to meet these requirements or to plan for periodic cleanout in order to maintain the capacity requirements. Where available sites do not lend themselves to meeting such design criteria, approval should be obtained form the Soil Conservation District and the responsible county agency to design and install a sediment basin with less storage.

NOTE:

Sediment basins shall be cleaned out when the effective storage capacity drops below 0.2 inch per acre of drainage area. The elevation corresponding to this level shall be determined and given in the design data as a distance below the top of thee riser. 0.5 inch of storage per acre of watershed equals 67 cubic yards per acre of watershed. 0.2 inch of storage per acre of watershed equals 27 cubic yards per acre of watershed.

<u>Spillway Design</u>

1. Runoff Computations - Combined capacity of the pipe and emergency spillways will, where applicable, be desinged to handle a ten-year frequency storm. Runoff will be figured by an acceptable method and should be based on soil cover conditions expected to prevail during the anticipated effective life of the structure.

2. Pipe Spillways - Disign the pipe spillway to handle not less than five inches runoff from the drainage area for 24 hours (i.e., five inches runoff or 0.21 cfs per acre of drainage area). (See Appendix A-2 for capacity of specific pipe combination.) The pipe spillway will consist of a vertical pipe or box type riser joined to a horizontal pipe (barrel) which will extend through the embankment. The riser will be perforated to provide a gradual drawdown in the reservoir to a planned elevation after each storm event. The hydraulic efficiency of the pipe spillway may be increased by using a riser with a cross sectional area of at least 1.5 times the cross sectional area of the horizontal pipe.

   a. <u>Crest Elevation</u> - When used in combination with emergency spillways, the crest elevation of the riser shall be at least one foot below the elevation of the control section of the emergency spillway. If no emergency spillway is provided, the crest elevation of the riser shall be at least three feet below the crest elevation of the embankment.

c. Antivortex Device - An antivortex device shall be used on the top of the riser if the discharge values in the appended charts are used. If no antivortex device is used, discharge values given in the charts must be reduced by 50 percent. An approved antivortex device is a thin, vertical plate normal to the centerline of the dam and firmly attached to the top of the riser. The plate dimensions are: length = diameter of the riser plus 12 inches; height = diameter of the horizontal pipe.

d. Base - The riser shall have a base attached with a watertight connection and shall have sufficient weight to prevent flotation of the riser. Two approved bases are: (1) A concrete base 18 inches thick with the riser imbedded six inches in the base. The base should be square with each dimension one foot greater than the riser diameter. (2) A 1/4 inch minimum thickness steel plate welded all around the base of the riser to form a watertight connection. The plate shall be square with each side equal to two times the riser diameter. The plate shall have two feet of stone, gravel, or tamped earth placed on it to prevent flotation.

e. Trash Rack - An approved trash rack shall be securely attached to the top of the riser.

f. Antiseep Collars - Conduits through embankments consisting of materials with low silt-clay fractions shall be provided with antiseep collars where the pipe diameter is 10 inches or greater. Seep length should be increased approximately 10 percent. All Class "B: basins shall have a minimum of one antiseep collar.

3. Emergency Spillway

a. Capacity - The minimum capacity for emergency (earth) spillway will be that required to pass the peak flow from design storm less any reduction creditable to the pipe spillway. Where emergency spillways are used, the channel bottom shall have a minimum width of eight inches. Design of emergency spillways can be determined through the use of Appendix A-3.

b. Maximum Allowable Velocity - The maximum allowable velocity in the exit channel shall be 6.0 feet per second.

c. Vegetative Protection - Provide for the protection of the embankment and emergency spillway by vegetative or other suitable means. See Standard and Specifications for Critical Area Stabilization.

4. Freeboard - Freeboard is the difference in elevation between design high water (10 year storm as outlined above) and the top of the settled embankment. Minimum freeboard shall be 1.0 feet for sediment basins with emergency spillways and 2.0 feet for those with no emergency spillway.

Embankment - The embankment shall have a minimum top width of eight feet. Side slopes shall be no steeper than 2:1 for the Class "X: sediment basins and no steeper than 2-1/2:1 for the Class "B: sediment basins. The maximum fill height shall be 10 feet for Class "X" basins and 15 feet for Class "B" basins.

Storage Area - Consideration should be given to fencing the sediment storage area.

CONSTRUCTION SPECIFICATIONS:

Site Preparation - Areas under the embankment and any structural works shall be cleared, grubbed, and the topsoil stripped to remove all trees, vegetation, roots, or other objectionable material. In order to facilitate cleanout and restoration, it is recommended that the pool area (measured at the top of the pipe spillway) be cleaned of all brush and trees.

Embankment

1. Material - The fill material shall be taken from approved designated borrow area or areas. It should be free of roots, woody vegetation, oversize stones, rocks, or other objectionable materials. The embankment shall be raised to an elevation which provides for anticipated settlement to design elevation (allow 10 percent for settlement).

2. Placement - Areas on which fill is to be placed shall be scarified prior to placement of fill. Fill materials shall be placed in six inch maximum lifts which are to be continuous over the entire length of the fill.

3. Compaction - The movement of the hauling and spreading equipment over the fill should be controlled so that the entire surface of each lift will be traversed by not less than one tread track of the equipment or compaction shall be achieved through use of a roller.

Pipe Spillway Installation - The riser must be rigidly and securely fastened to the barrel and the bottom of the riser must be sealed (watertight). The pipe spillway shall discharge at ground elevation below the dam. All pipe joints must be securely fastened and watertight.

Emergency (earth) Spillway Installation - Emergency spillways must be installed and on undisturbed soil (not on fill) by grading. Entrance and exit channels grade must equal design grades; length of level control section will be 10 feet; channel side slopes will be not steeper than 2:1.

Structural Backfill - Backfill material shall be of the type and quality conforming to that specified for the adjoining fill material. The material shall be placed in maximum six inch lifts and hand compacted to equal or exceed the density of the adjoining fill.

INFORMATION TO BE SUBMITTED FOR APPROVAL:

Sediment Basin designs submitted for review to the Soil Conservation District and construction plans submitted to the responsible county agency will include the following:

a. Specific location of the dam

b. Plan view of dam and the storage basin

c. Cross section of dam and emergency spillway; profile of emergency spillway

d. Runoff calculations for 10-year storms.

e. Calculations showing design of pipe and emergency spillway

f. Storage Computation (stated in acre feet)

    1. Total required (acre feet)

    2. Total available (acre feet)

    3. Level of sediment when storage drops below 0.2 inches per acre of drainage area

NOTE:

Items d through f above may be submitted using a design data sheet similar to that shown in Appendix A-4.

SEDIMENT BASIN CONSTRUCTION AND MAINTENANCE CRITERIA:

The following are critical to successful installation and operation of Sediment Basins:

a. Locate the dam to provide maximum volume capacity for silt behind the structure.

b. Prepare the dam site by adequate clearing of vegetation and removal of topsoil before beginning dam construction.

c. Level the bed for the pipe spillway to provide uniform support throughout its entire length under the dam.

d. Securely and rigidly fasten the collar connecting the riser to the barrel (as well as collars connecting sections of the barrel) of the pipe spillway; insure a watertight bottom on the riser; hand tamp fill under shoulders and around the pipe; insure that outlet invert of pipe spillway is not more than one foot above streambed.

e. Place the fill in not more than six-inch lifts compacted by construction equipment. A minimum of two (2) feet of hand compacted backfill shall be placed over the pipe spillway before crossing it with construction equipment. Fill materials should be free from roots, woody vegetation, oversize stones, rocks, or other objectionable material. Frozen material should not be used.

f. Construct emergency spillway as per design on undisturbed soil (not on fill). Design width and entrance and exit channel slopes are critical to the ability of the emergency spillway to successfully protect the dam with a minimum of erosion hazard in the spillway channel.

g. Stabilize embankment and emergency spillway by treatment (lime and fertilizer) sodding or seeding and mulching.

h. When trap efficiency drops below 0.2 inch per acre of drainage area, the sediment basin should be cleaned out to store its original capacity.

MAINTENANCE:

Inspect after each storm. Remove sediment each and every time the structure capacity has been reduced by the factor determined in structure design. Sediment must be disposed of or stabilized in a manner that will preclude its return to downstream areas during storm runoff events.