



Estimated costs of spoil bank reclamation alternatives
by Myles James Watts

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE
in Applied Economics
Montana State University
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Abstract:

The major objective of this study is to estimate surface reclamation cost and compare reclamation costs of various reclamation alternatives.

Cost estimates are generated for alternative reclamation goals of grazing, dryland crop, and various combinations of grasslands and trees. Costs are estimated for recontouring of strip mine spoils to various slopes.

The influence on reclamation cost of the depth of topsoil salvaged and redistributed on the recontoured spoils and the effect of overburden depth on reclamation cost are also estimated.

Farm budgeting is used to estimate the reclamation costs. Recontouring costs are a function of the volume of spoils moved and the distance the spoils must be moved. The volume of spoils moved is estimated using a cross-sectional approach.

Some variables have a larger influence on reclamation cost than other variables. Overburden depth has a large influence on reclamation cost. The reclaimed slope has a small influence on reclamation cost if the overburden depth is small (7.04 yards); however, as the overburden depth increases, so does the influence of the reclaimed slope on reclamation cost. (The range of reclaimed slopes considered are from 0% - 20%.) As the highwall height increases or the reclaimed high-wall slope decreases, the cost of recontouring the highwall increases.

The influence of highwall recontouring costs on the reclamation cost per acre varies widely due to mine design along with the highwall height and reclaimed highwall slope. The cost of topsoiling varies directly with the depth of topsoil desired. Topsoiling costs are a significant portion of reclamation cost if only 2 inches of topsoil are desired on the reclaimed surface. (As topsoil depth increases on the reclaimed surface, topsoiling cost assumes a larger portion of reclamation cost.) Reclamation goal may or may not have a large influence on reclamation cost. Changing the reclamation goal from grazing to cropland has a minor influence on reclamation costs while including trees (in great numbers) in the reclamation goal will significantly increase reclamation cost.

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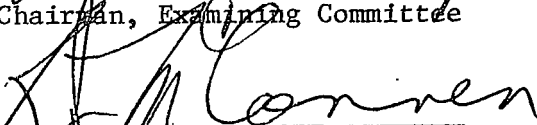
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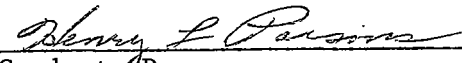
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Approved:


Chairman, Examining Committee


Head, Major Department


Graduate Dean

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TABLE OF CONTENTS

	Page
LIST OF TABLES.	vi
LIST OF FIGURES	viii
CHAPTER	
1. Introduction	1
Objective.	2
Limitations of the Study	3
Thesis Design.	5
Law.	5
2. Description of Mining Process, Reclamation Process, and Variables to be Considered Which Influence Reclamation Cost	8
Reclamation Process.	8
3. Recontouring of Strip Mine Spoils.	15
4. Topsoiling	24
Method of Determining the Volume of Topsoil Moved and Influences of the Recontoured Slope on Volume of Topsoil Salvaged and Redistributed.	25
Method of Determining the Distance Topsoil is to be Moved	29
5. Revegetation, Miscellaneous and Unallocated Cost . .	34
Estimation of Revegetation Costs	34
Miscellaneous and Unallocated Costs.	41
6. Reclamation Cost Examples.	43
Generation of Recontouring Cost.	43
Topsoiling Cost.	47
Generation of Revegetation, Miscellaneous, and Unallocated Costs.	52
Assumptions for Cost Examples.	56
7. Summary, Conclusions, and Comments	75
Summary.	75
Conclusions and Comments	80

APPENDIX A.	82
APPENDIX B.	114
APPENDIX C.	119
BIBLIOGRAPHY.	123

LIST OF TABLES

TABLE		PAGE
4.01	Conversion Factors for the Differences Between Horizontal Area and Surface Area Relative to Various Average Surface Slopes	27
5.01	Machinery Cost Estimates for Dryland Crop and Grazing.	36
5.02	Representative Revegetation Seed Mixture for Grazing.	37
5.03	Revegetation Cost Summary for Dryland Crop and Grazing.	39
5.04	Revegetation of Cost Summary for Grazing (Aerial and Farm Machinery Seeding).	39
5.05	Cost of Planting a Tree.	40
6.01	Machinery Cost for Recontouring.	54
6.02	Machinery Cost for Topsoiling.	55
	Cost Summary of Reclamation Alternatives	
6.03	Cost Summary	57
6.04	Cost Summary	58
6.05	Cost Summary	59
6.06	Cost Summary	60
6.07	Cost Summary	61
6.08	Cost Summary	62
6.09	Cost Summary	63
6.10	Cost Summary	64
6.11	Cost Summary	65

TABLE		PAGE
6.12	Cost Summary	66
6.13	Cost Summary	67
6.14	Cost Summary	68
6.15	Cost Summary	69
6.16	Cost Summary	70
6.17	Cost Summary	71
6.18	Cost Summary	72
6.19	Cost Summary	73
6.20	Cost Summary	74
7.01	Reclamation Cost/acre of Various Overburden Depths and Reclaimed Slopes.	75
7.02	Recontouring Cost of the Highwall in Regard to Various Highwall Heights and Reclaimed Highwall Slopes.	77
7.03	Reclamation Cost/acre of Various Overburden Depth and Topsoil Depths	78
7.04	Reclamation Cost/acre of Various Reclamation Goals.	79
B.01	Machinery Cost Estimates for Seedbed Preparation, Seeding and Fertilizing (banding), and also Fertilizing (broadcasting)	115
B.02	Inflationary Factor for Updating Machinery Cost Estimates	116
B.03	Estimates Per Acre Machinery Costs for Revegetation	117
B.04	Machinery Cost Estimates for Tree Planting (Tublings)	117
B.05	Estimated Machinery Cost Per Tubling Planted . . .	118

LIST OF FIGURES

FIGURE		PAGE
2.01	General Contour of the Post-Mining Contour and On-going Reclamation	9
2.02	Cross-section of Spoil Banks	11
2.03	Illustration of Slope of General Area in Regard to Recontouring	12
3.01	General Contour of Mining Area	17
3.02	Cross-section of Mining Area	18
3.03	Cross-section of Ramp Road	19
3.04	Cross-section of Highwall Area	20
3.05	Cross-section of Highwall Area	21
4.01	Diagram of Slope Effect on Area.	25
4.02	Diagram of Area to be Topsoiled.	30
4.03	Diagram of Topsoil Area in Initial Spoil Bank Area	31
A.01	Cross-section of Initial Spoil Bank Area - Actual Post-mining Contour	83
A.02	Cross-section of Initial Spoil Bank Area - Assumed Post-mining Contour.	83
A.03	Cross-section of Initial Spoil Bank.	84
A.04	Labeled Cross-section of Initial Spoil Bank Area .	85
A.05	Cross-section of Highwall Area Variation 1	90
A.06	Cross-section of Highwall Area Variation 2	90
A.07	Labeled Cross-section of the Highwall Area Variation 2.	92
A.08	Cross-section of the Highwall Area to Determine Highwall Width	95

FIGURE		PAGE
A.09	Cross-section of the Highwall Area	96
A.10	Labeled Cross-section of Highwall Area	98
A.11	Cross-section of Undisturbed Area to be Moved in Highwall Area	101
A.12	Cross-section of Ramp Road	102
A.13	Cross-section of Remaining Spoil Banks Produced from Less than 5.12 Yards of Overburden.	104
A.14	Cross-section of Remaining Spoil Banks Produced from Greater than 5.12 Yards of Overburden	104
A.15	Cross-section of Remaining Spoil Banks Produced from Less than 5.12 Yards of Overburden Showing Recontoured Slope.	105
A.16	Cross-section of Assumed and Actual Post-mining Contour Remaining Spoil Bank Area.	105
A.17	Cross-section of a Spoil Bank.	106
A.18	Labeled Cross-section of Remaining Spoil Bank Area	107
A.19	Labeled Cross-section of Remaining Spoil Bank Area	108
A.20	Cross-section of Remaining Spoil Bank Area	111
C.01	Diagram to Determine Width of Recontoured Slope on the Highwall Side of the Highwall Area.	120
C.02	Cross-section of the Yardage Displaced by the Ramp Road.	121

ABSTRACT

The major objective of this study is to estimate surface reclamation cost and compare reclamation costs of various reclamation alternatives. Cost estimates are generated for alternative reclamation goals of grazing, dryland crop, and various combinations of grasslands and trees. Costs are estimated for recontouring of strip mine spoils to various slopes. The influence on reclamation cost of the depth of topsoil salvaged and redistributed on the recontoured spoils and the effect of overburden depth on reclamation cost are also estimated.

Farm budgeting is used to estimate the reclamation costs. Recontouring costs are a function of the volume of spoils moved and the distance the spoils must be moved. The volume of spoils moved is estimated using a cross-sectional approach.

Some variables have a larger influence on reclamation cost than other variables. Overburden depth has a large influence on reclamation cost. The reclaimed slope has a small influence on reclamation cost if the overburden depth is small (7.04 yards); however, as the overburden depth increases, so does the influence of the reclaimed slope on reclamation cost. (The range of reclaimed slopes considered are from 0% - 20%.) As the highwall height increases or the reclaimed highwall slope decreases, the cost of recontouring the highwall increases. The influence of highwall recontouring costs on the reclamation cost per acre varies widely due to mine design along with the highwall height and reclaimed highwall slope. The cost of topsoiling varies directly with the depth of topsoil desired. Topsoiling costs are a significant portion of reclamation cost if only 2 inches of topsoil are desired on the reclaimed surface. (As topsoil depth increases on the reclaimed surface, topsoiling cost assumes a larger portion of reclamation cost.) Reclamation goal may or may not have a large influence on reclamation cost. Changing the reclamation goal from grazing to cropland has a minor influence on reclamation costs while including trees (in great numbers) in the reclamation goal will significantly increase reclamation cost. ✓

Chapter 1

Introduction

(The Montana Coal Task Force estimated that the mining of "Montana's strippable (coal) reserves could disturb a maximum of about 770,000 acres."¹ Between 1968 and 1973, approximately 683 acres were disturbed in Montana by coal mining. It has been estimated that by the year 1980, 8,493 acres will be disturbed and by the year 2000, 209,540 acres will be disturbed by coal mining in Montana.² Therefore, a sizeable area may be disturbed by coal mining in the next 25 years.) Presently most of the coal mined in Montana is strip mined in which the material overlying the coal seam (overburden) is "stripped" off, exposing the coal seam, and the coal is removed. The overburden is placed as spoil after being stripped from above the coal seam; strip mined spoil banks have been labeled as unacceptable by portions of our society. Reclaiming the spoils to a productive state hopefully makes them more acceptable. It has been projected that 735 acres will be strip mined in 1975 in Montana.³ If only \$1000 per acre is spent for reclamation,

¹ Montana Coal Task Force, "Coal Development in Eastern Montana", January 1973, p. 14.

² Montana Energy Advisory Council, Lt. Governor of Montana Bill Christiansen, Chairman, Coal Development, December 1974, p. 53,54. Most probable estimates of future acreage disturbances used.

³ News Release, Christiansen, Bill, Lt. Governor of Montana, January 1975.

then the total cost of reclamation in 1975 in Montana will be \$735,000.⁴ Therefore a sizeable amount of money is being spent on reclamation and the amount of money spent on reclamation apparently will increase as the rate of strip mining increases. Reclamation alternatives (as explained in the next section) do exist and these alternatives do incur differing costs. If large amounts of money are to be spent on reclamation, then decision-makers should view the benefits and costs of reclamation to choose a reclamation alternative. ✓

Objective

The major objective of this study is to estimate reclamation costs and compare reclamation costs of various reclamation alternatives. Reclamation as referred to in this study is surface reclamation. Surface reclamation includes recontouring of the strip mine spoils, stabilizing the surface, and providing a stable and productive vegetative cover. ✓

Cost estimates will be generated for various alternative reclamation goals. The reclamation goals considered are dryland crop, grazing, and combinations of grassland and trees. Winter wheat will be used to represent the dryland crop, as winter wheat is the major dryland crop grown in Montana in general, and particularly in the coal area.

The post-mining contour may be recontoured to various slopes. Therefore, cost estimates will be generated for various recontoured

⁴\$1000 per acre is probably a minimum figure for reclamation cost as is illustrated in later chapters.

slopes at varying overburden depths.⁵

Economics is the science of choice. If decision-makers have perfect knowledge, then optimal decisions or choices could be made. However, perfect knowledge is generally not the case, so information presented in this study may make decision-makers more knowledgeable to choose among reclamation alternatives. Emphasis is placed on difference in cost among reclamation alternatives, rather than the total costs, although total cost estimates are presented. Economically speaking, in decision-making the cost differentials among alternatives (along with the differences in benefits) are the basis for determining the optimum alternative (or alternatives).

Limitations of the Study

The reclamation cost estimates generated in this study are applicable to Eastern Montana. All or certain portions of this study may be applicable to other areas depending upon the similarity of characteristics of other areas to those in Montana.⁶ Certain areas within Montana have characteristics which may cause estimated reclamation costs presented to be grossly understated. Revegetation may be inhibited by lack

⁵For those not familiar with the post-mining contour and recontoured slope, a description of the post-mining contour, reclaimed contour, mining process, and reclamation process will be presented in Chapter 2.

⁶Similarity must include climate, soil type, vegetation which can be grown, and environment. However, portions of the study may apply to dissimilar areas. For example, the cost estimates (and method of determining cost) for recontouring may apply to any area if the post-mining contour and other factors are similar.

of sufficient or suitable water. The overburden may be unsuitable as a base for topsoil, inhibiting revegetation and thus influencing reclamation cost.

Other factors which may cause the estimates of reclamation costs presented to be inaccurate are use of equipment other than that assumed in this study, seasonality of certain activities within the reclamation process, and the occasional occurrence of a drought or other unusual weather problem. Often whatever equipment is available will be used for reclamation purposes rather than the bulldozer and scraper assumed in this study. For instance, a dragline may be used for highwall reduction rather than the assumed bulldozer. Use of equipment other than the assumed equipment may incur different costs and therefore cause reclamation costs to differ from the presented estimates. Some activities in the reclamation process are seasonal which influences reclamation cost. For example, grass seeding is seasonal and can only be accomplished, if revegetation is to be successful, at certain times of the year. Specific years may allow greater time for seasonal activities than others due to yearly fluctuation in temperature and moisture available in the soil. The increased reclamation cost due to seasonality is difficult to estimate and therefore a "lump sum" allowance has been made for seasonality in Chapter 5 under "Miscellaneous and Unallocated Costs." In certain years revegetative problems may occur which do not occur in average years. Poor response to revegetative

efforts may cause duplication of revegetative efforts and increased reclamation costs. Problems which cause a poor response to revegetation efforts include drought, short growing seasons, and extreme erosion from wind and water.

Thesis Design

Farm budgeting is used to generate reclamation cost estimates. In recontouring and topsoiling, the yardage to be moved must be estimated to obtain reclamation costs. A cross-sectional approach is used to estimate the yardage moved.

Chapter 2 explains the mining and reclamation process, the variables considered in this study when estimating reclamation costs, and defines terms as used in this study. Chapter 3 presents the method used to estimate the cost of recontouring strip mine spoils. Topsoiling costs are estimated in Chapter 4 and revegetation, miscellaneous, and unallocated costs are estimated in Chapter 5. In Chapter 6, an example is presented to illustrate the entire process of estimating the cost of reclamation and estimated reclamation cost of several reclamation alternatives. Chapter 7 compares reclamation costs of various reclamation alternatives, discusses needs for further research, and includes some comments from the author.

Law

The State of Montana has prescribed certain requirements which ✓

must be met when reclaiming strip mined lands. The maximum acceptable reclaimed highwall slope is 20° or 36.41% (which is approximately three units of horizontal distance for each unit of vertical distance). The area must be contoured to approximate the original contour. All available topsoil must be removed and kept in such a condition as to sustain vegetation of at least the quality and of the same diversified varieties as the topsoil sustained prior to its removal. The topsoil must be returned to cover the mined area after recontouring unless another layer of material in the overburden is substituted which is equally capable of supporting vegetation. The soil shall have been prepared such that "legumes, grasses, shrubs, and trees upon the area of land affected" will produce and sustain a "suitable permanent diverse vegetative cover capable of:

- a) feeding and withstanding grazing pressure from a quantity and mixture of wildlife and livestock at least comparable to that which the land could sustain prior to the operation (mining);
- b) regenerating under the natural conditions prevailing at the site, including occasional drought, heavy snowfall and strong winds; and
- c) preventing soil erosion to the extent achieved prior to the operation (mining)."⁷

Cost estimates are generated for procedures which are intended to meet the present surface reclamation law of the State. Cost estimates

⁷ Codes of Montana, Section 50-1044, passed 1974, both paraphrased and directly quoted.

are also generated which may conflict with present Montana reclamation laws. Over the long run, laws may be changed, therefore cost estimates outside the law may be useful.

Chapter 2

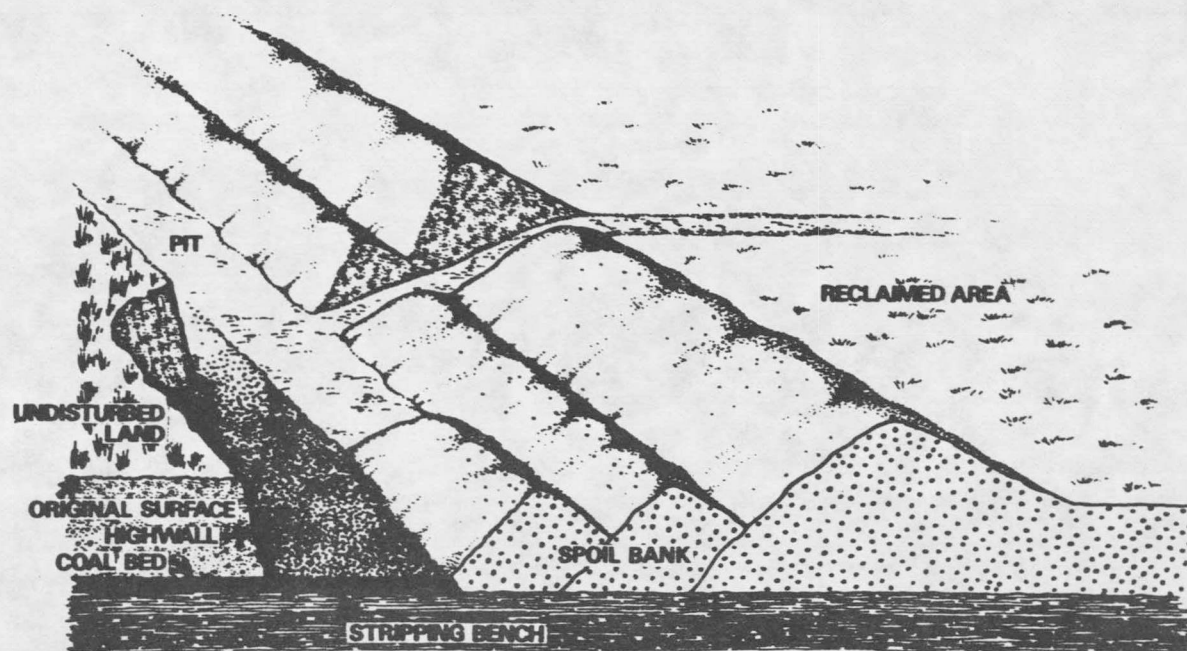
Description of Mining Process, Reclamation Process, and Variables to be Considered which Influence Reclamation Cost

Area strip mining is practiced in relatively flat terrain while contour strip mining is practiced on rolling to very steep terrain. In area strip mining, a trench or boxcut is made through the material covering the coal (overburden) to expose the coal to be removed and the boxcut is extended as far as desired. The overburden from this first cut is placed on the land adjacent to the cut. The coal is removed. After the first cut is completed and the coal is removed, a second cut is made parallel and adjacent to the first cut, and the overburden from the succeeding cuts is deposited in the previous cut. The deposited overburden is called spoils and the parallel ridges of spoils are referred to as spoil banks. The last cut leaves a trench bounded on one side by the last spoil bank and on the other by a highwall equal in height to the thickness of the overburden and the coal seam. Refer to Figure 2.01.

Reclamation Process

The reclamation process begins with salvaging the topsoil before the overburden is "stripped" off. After the topsoil has been salvaged, the overburden stripped off, and the coal removed, the spoil banks are

Figure 2.01. General Contour of the Post-mining Contour and On-going Reclamation.



recontoured to the desired slope or contour. After recontouring, the topsoil is placed back on the surface and the area is revegetated.

Reduction of slope of the spoil banks and highwall is important ✓ to reduce erosion and encourage vegetative establishment. It has been estimated that as the percent of recontoured slope doubles, soil loss increases by 2.6 times.⁸ Topsoiling is extremely important if revegetation is to be successful, unless a layer of material within the overburden is chemically and physically suitable and is placed on the surface. Even if raw materials (after recontouring) can be revegetated, in most cases the additional cost of amendments, replanting of bare spots, and extended maintenance of revegetated areas is greater than topsoiling costs.⁹ Revegetation is composed of seedbed preparation, ✓ seeding or planting, and fertilization. Seeding is important to establish desirable species and to control erosion. Fertilization is a necessity to establish optimum vegetation in most cases.¹⁰

A cross-sectional approach will be used to determine the volume of overburden to be moved in recontouring. The reclaimed contour used

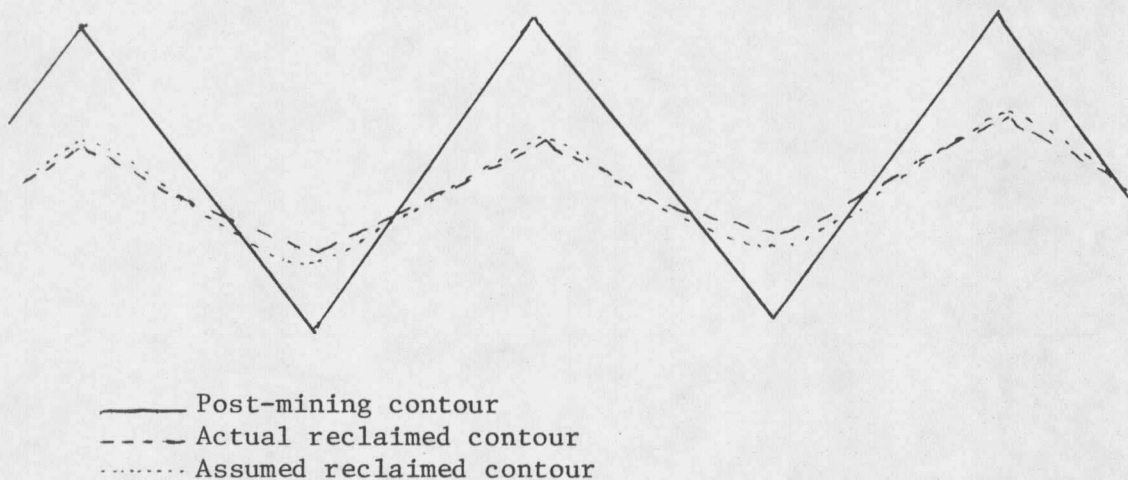
⁸ Environmental Protection in Surface Mining of Coal, Environmental Protection Technology Series, EPA-670/2-74-093, October 1974, p. 151.

⁹ Ibid, p. 168.

¹⁰ Sindelar, Brian, W., Hodder, Richard L., Majerus, Mark E., Surface Mined Land Reclamation in Montana, Research Report 40, Montana Agricultural Experiment Station, Montana State University, Bozeman, Montana, April 1973, p. 46-47.

to estimate the volume of overburden moved and to estimate recontouring costs is only an approximation of the actual reclaimed contour. The distinct angular contour of the reclaimed contour used to estimate the volume of overburden moved is actually more rounded because the overburden is moved with a dozer. The actual and the assumed contours are illustrated in Figure 2.02.

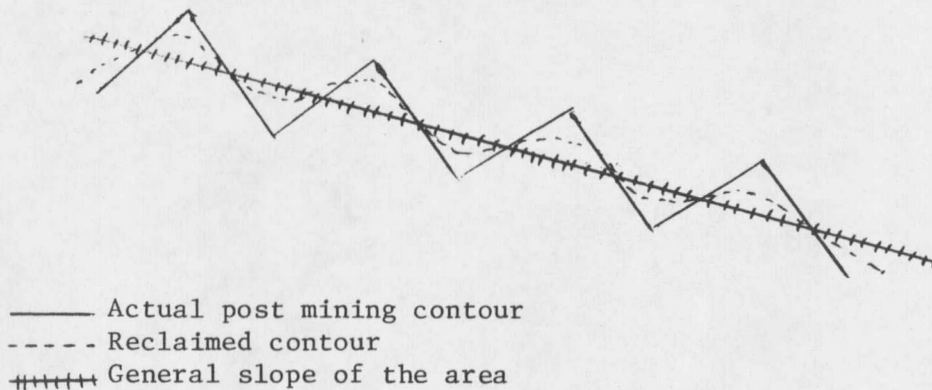
Figure 2.02. Cross-Section of Spoil Banks



In later chapters, slope is expressed as a percentage. The slope in terms of percentage is found by dividing the run (horizontal distance) into the rise (vertical distance). The slope is in terms of deviation from the general slope of the surrounding area. For further clarification, refer to Figure 2.03.

For purposes of this study, it is assumed that the overburden is of sufficient quality to provide an acceptable base upon which to

Figure 2.03. Illustration of Slope of General Area
in Regard to Recontouring



deposit the topsoil and support vegetation. Also, this study assumes that there is sufficient depth and quality of topsoil on the post mining area to provide the desired topsoil on the recontoured spoils.

Description of Variables Which Influence Reclamation Cost

Mining and reclamation should be viewed as one continuous process ✓ if the process is to be carried out in a timely and orderly manner.¹¹ For purposes of this study, each activity within the reclamation mining process directly related to reclamation (recontouring, topsoiling, and revegetation) will be costed separately, but with regard to other

¹¹Environmental Protection in Surface Mining of Coal; Environmental Protection Technology Series, EPA-670/2-74-093 October 1974, p. 17.

reclamation and mining activities.

Costs which are directly associated with reclamation activities of recontouring, topsoiling and revegetation will be estimated. The variables considered which influence recontouring costs are the amount of overburden to be moved (a function of the recontoured slope) and the distance the overburden is to be moved. Topsoiling costs are influenced by the amount of topsoil salvaged and redistributed, the distance the topsoil is to be moved, and the amount of topsoil to be stockpiled. Revegetation costs depend upon the revegetation goal, seed-bed preparation, type of plants desired, and the amount of fertilizer used. In each activity there are other influences which affect reclamation cost but these are the most important variables influencing reclamation costs and are the variables considered in this study. ✓

Costs which are not included in this study include the cost of information and data gathering activities. For instance, the costs of soil sampling and preparation of impact statements are not considered. Costs of research, the training or hiring of professional personnel (experts in the area of reclamation), and the increased cost to the mining portion of the process (if such does occur) have not been subsumed in the cost estimates presented. Only those activities directly related to reclamation have been included.

Areas associated with the area to be strip mined are also disturbed. ✓
Among these associated areas are the tipple area, the railroad loop,

other roads and administrative buildings which may also need reclamation.

The cost of reclaiming the associated areas is not estimated in this study.

Chapter 3

Recontouring of Strip Mine Spoils

If the contour of the strip mine spoils is to be changed, then certain costs will be incurred. Through manipulation of the spoil banks, highwall, and ramp road, the contour can be changed. Ramp roads run through and perpendicular to the spoil banks to the level of the coal seam and extend to the mining pit. The major variables affecting the cost of recontouring are: the volume of spoils moved, the distance the spoils are moved, and the type of machinery used. Other variables such as operator efficiency, operator wages, characteristics of the particular spoil (i.e. rock versus sand), overhead cost, whether or not the machine is used exclusively for reclaiming or also for other work, and management costs also affect recontouring cost. In this particular model, the cost estimates for moving a cubic yard of spoil banks will be estimated through methods prescribed in the Caterpillar Performance Handbook.¹² All spoil banks will be assumed to be reshaped with a D9 Caterpillar track-type tractor with a universal dozer. The D9 Caterpillar may or may not be the least cost machine for spoil bank manipulation. However, the D9 (or similar machine) is being used at several mines.

¹²Caterpillar Performance Handbook 5th Edition, Caterpillar Tractor Company, January 1975.

For the purpose of determining the volume of overburden to be moved, the mining area was divided into four areas. These areas are the initial spoil bank, the final highwall, the ramp roads, and the remaining spoil bank areas. Reference to Figures 3.01, 3.02 and 3.03 may be helpful. The initial spoil bank area, the highwall area, and the remaining spoil bank area must equal the total area. If the area of the highwall, and the initial spoil bank area can be found, then the area of remaining spoil banks can be found. The volume of yardage to be moved will be found by equating the area to be filled with the area to be moved, using the cross-sectional illustrations to help estimate these volumes.¹³

The post mining contour for the highwall area and the initial spoil bank are difficult to work with geometrically. Using the highwall area as an example (the same argument can be used for the initial spoil bank area), and referring to Figures 3.04 and 3.05, we note that the yardage to be moved is in the same vicinity (from Point A to Point B) in both cross-sections. In the assumed and actual contour, the yardage moved to produce the desired contour is the same. (In the assumed contour area CDE is equal to area EFG in the actual contour by equal triangles.) However, the yardage is moved a greater distance in the

¹³ The derivation of the model for estimating the yardage moved in each area may be found in Appendix A.

Figure 3.01. General Contour of Mining Area

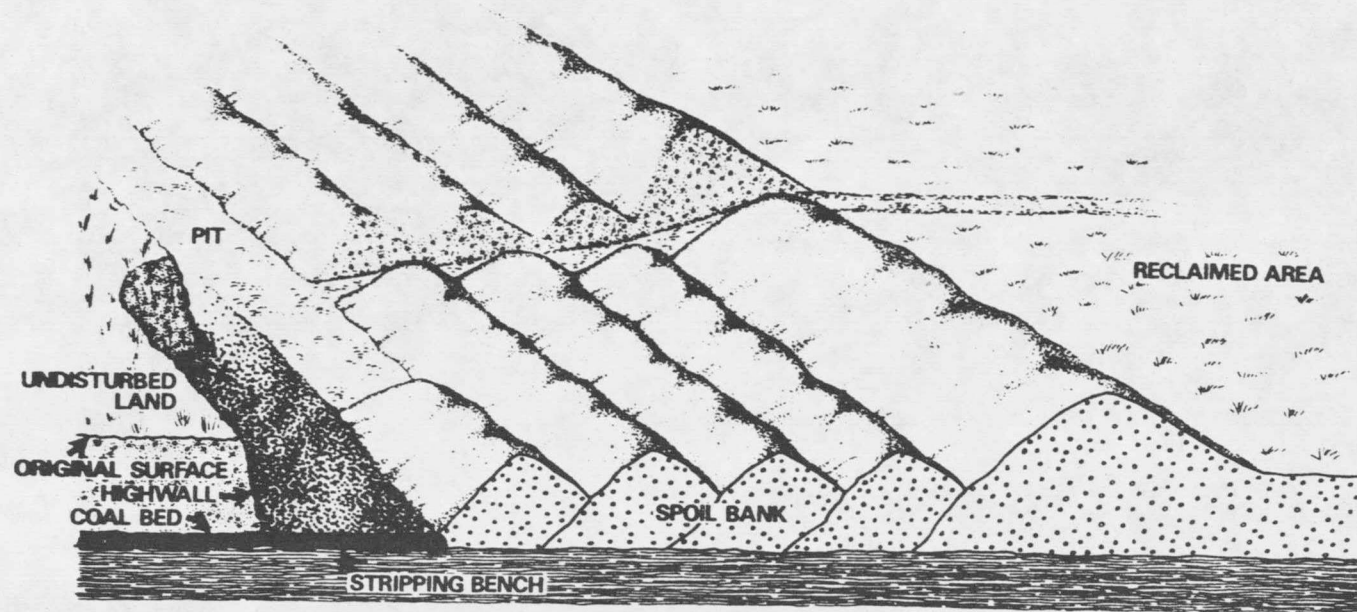


Figure 3.02. Cross-Section of Mining Area

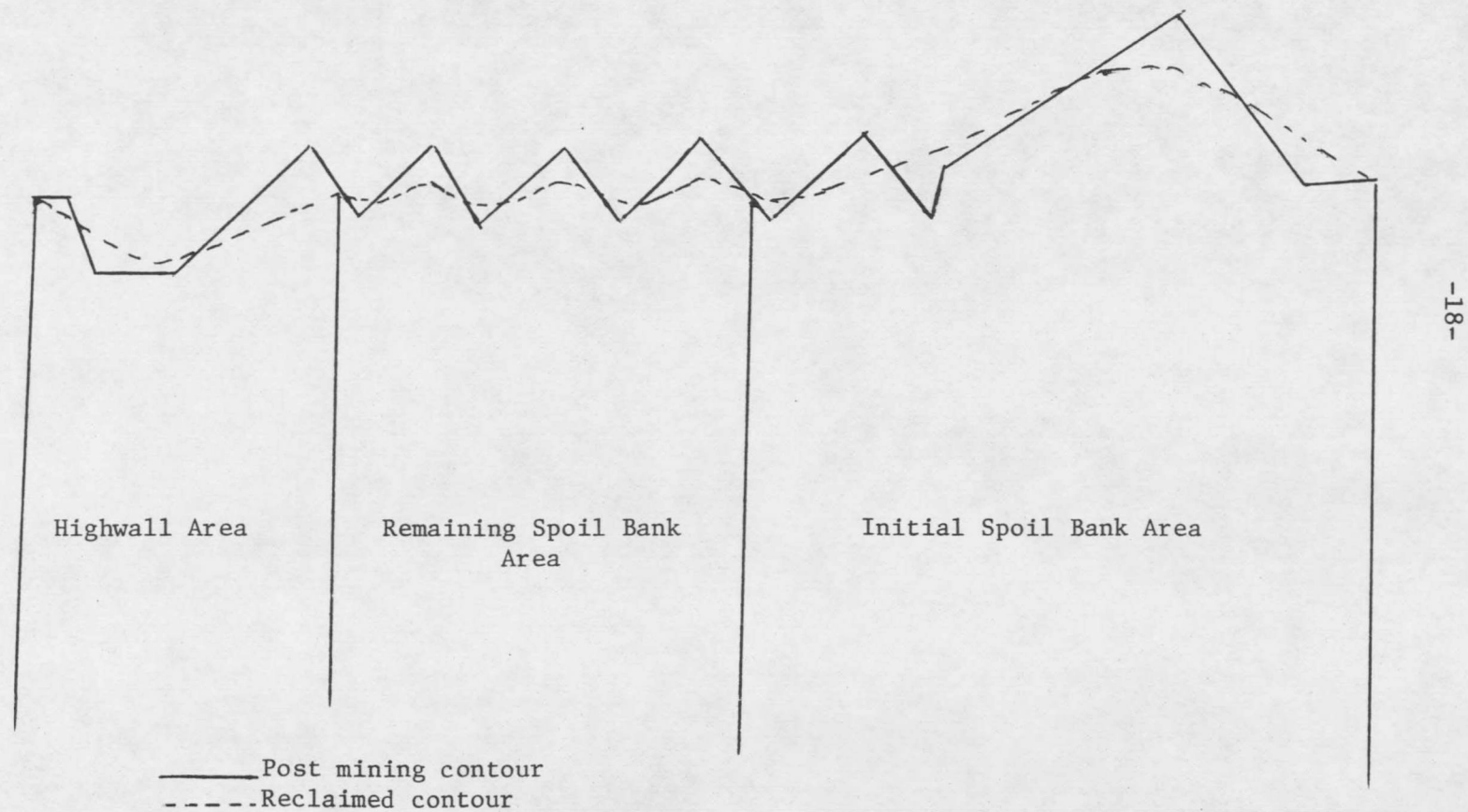
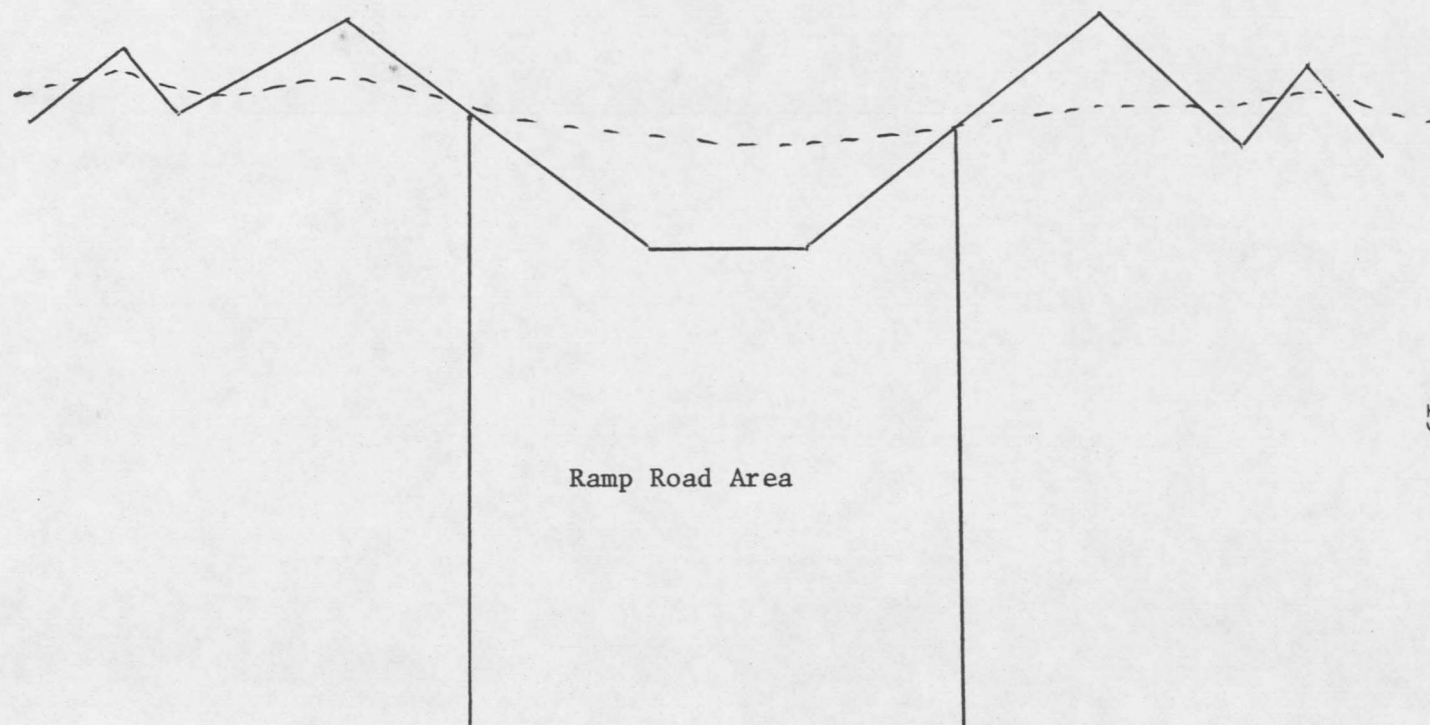


Figure 3.03. Cross-Section of Ramp Road



Ramp Road Area

—— Post mining contour
----- Reclaimed contour

Figure 3.04. Cross-section of Highwall Area

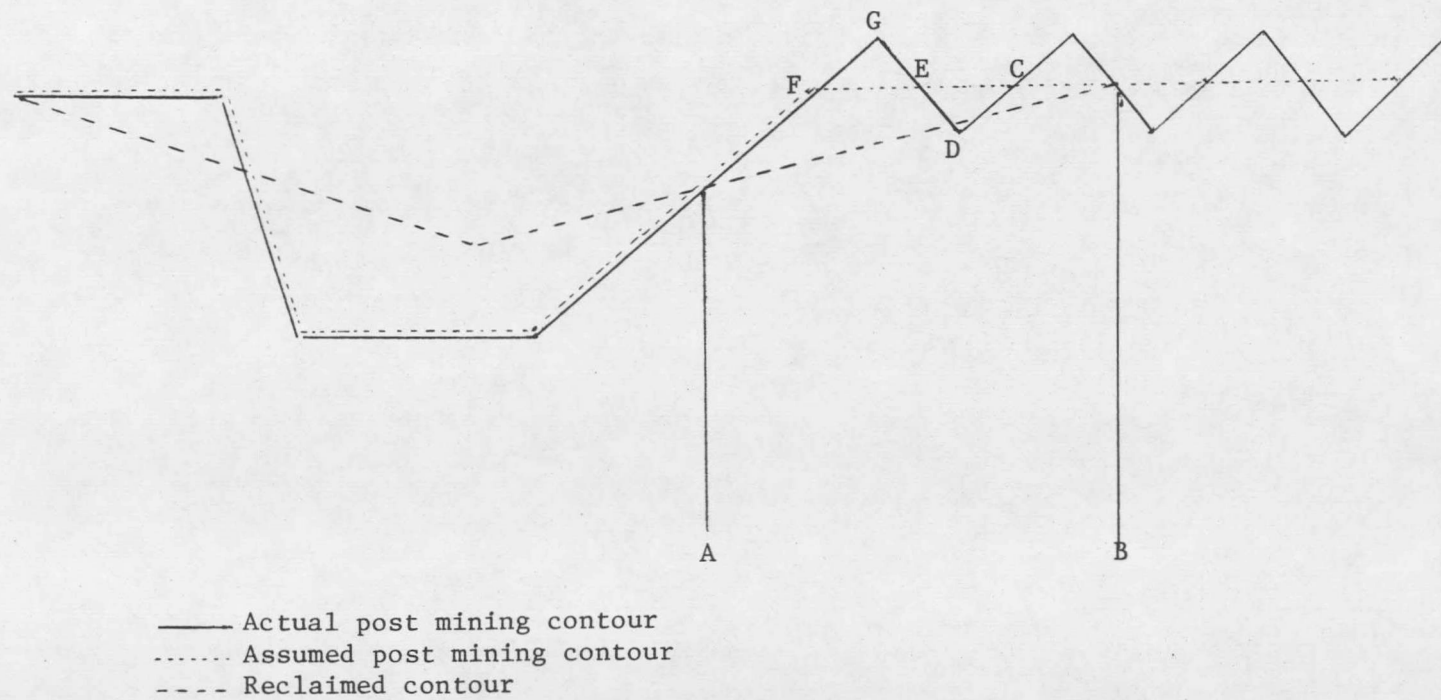
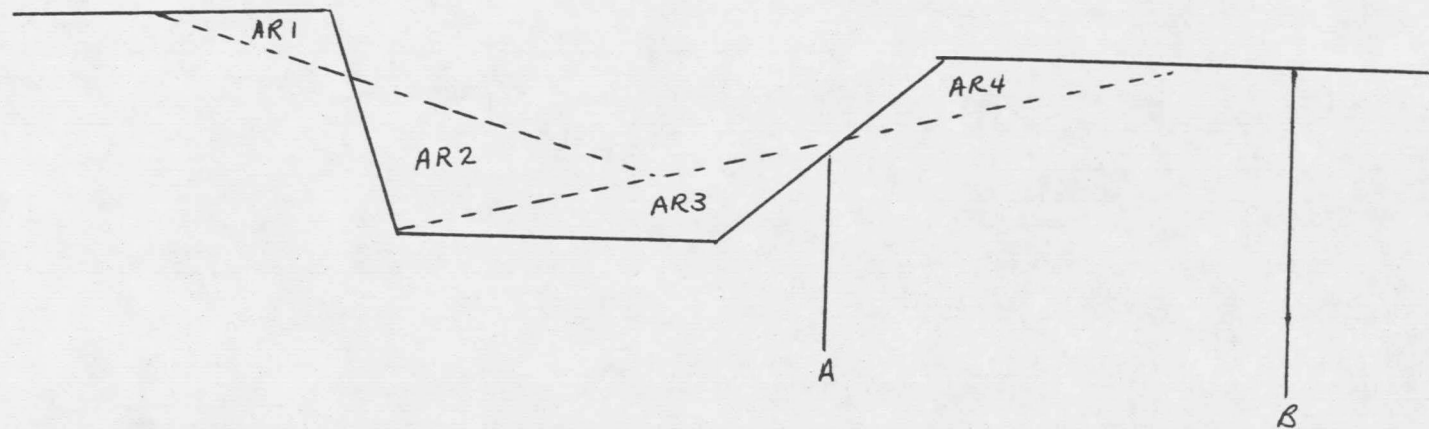


Figure 3.05. Cross-Section of Highwall Area



—— Post mining contour
--- Reclaimed contour

assumed contour.

By equating the area to be moved with the area to be filled, the yardage to be moved can be found. Therefore, referring to Figure 3.05, $AR3 = AR4$ and $AR1 = AR2$. (Actually, since $AR1$ has not been previously disturbed, $AR1$ will swell when moved,¹⁴ so $AR1 (1 + \text{swell factor}) = AR2$). The area moved from the highwall side must be equal to $AR2$ and the area moved from the overburden side must equal $AR3$. This method would appear to be the least cost method because:

- a) no yardage is moved uphill;
- b) the yardage moved from the highwall side is in general more expensive to move because it has not previously been disturbed and is more likely to need blasting or ripping. (This model assumes that all previously undisturbed overburden needs ripping.)

More explanation of what certain variables mean as referenced in the appendix and later chapters may be helpful. Overburden depth is the thickness of the material over the coal layer or seam. The overburden depth may be found in the core sample data. Overburden depth may vary over the area mined and costed. If the core samples were taken on regular intervals, then an average overburden depth can be found. If the core samples were not taken at regular intervals, then a weighted average may be more appropriate. The spoil bank depth is considered to be uniform in the highwall area, ramp road area, and

¹⁴When overburden is moved, the overburden will swell. The amount the overburden swells when moved is known as the swell factor.

initial spoil bank area because of the assumed contour. Realistically the spoil bank depth is not uniform. The depth of the spoil banks may be defined as the average distance between the surface and the bottom of the pit after the coal has been removed. The assumed spoil bank depth may be found by multiplying the overburden depth before mining by 1 plus the swell factor.

Chapter 4

Topsoiling

During the process of mining and reclamation, recontouring and topsoiling must be coordinated.

The following procedures provide a method of determining topsoiling cost under optimum conditions and assumes that topsoiling can be done at certain times of the year to provide for erosion control, weed control, transplant advantage, and to make seeding and stabilization of topsoil possible. Mining proceeds at a consistent rate not being affected to any large extent by the seasons or the time of the year. Therefore, the procedure to find a cost estimate for topsoiling cost as presented in this chapter is a minimum estimate of topsoiling cost and probably not the average cost of topsoiling. In a later chapter, under miscellaneous and unallocated costs, \$100 per acre have been added to reclamation costs, part of which is to allow for not topsoiling under optimum topsoiling conditions.

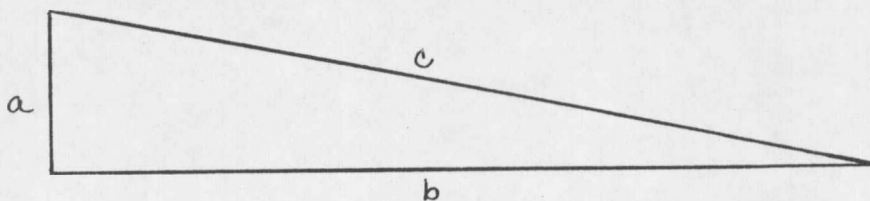
If the topsoil is to be placed back on the surface after mining, then the topsoil must be salvaged before strip mining and redistributed after the spoil banks are recontoured. The cost of topsoil salvaging and redistribution depends on the volume of topsoil moved per acre, the distance the topsoil must be moved, the type of machine used, and the operating cost of that machine. (Other variables also affect

cost but the aforementioned variables are the ones considered in this study.)

Method of Determining the Volume of Topsoil Moved and the Influence of the Recontoured Slope on Volume of Topsoil Salvaged and Redistributed.

The volume of topsoil salvaged and redistributed per acre depends on the depth of topsoil available and the desired thickness placed on the reclaimed contour. The original contour and the reclaimed contour affect the volume of topsoil salvaged and redistributed. For example, if the land is recontoured such that the average slope is 0.20, then more topsoil must be salvaged to redistribute than if the contour slope is 0 or the reclaimed contour is flat. (Figure 4.01)

Figure 4.01. Diagram of Slope Effect on Area



If we assume that $b = 100$ yards and the recontoured slope equals 0.20, then $a = 20$ because:

$$\text{Reclaimed contour slope} = a/b$$

$$a = (b) (\text{reclaimed contour slope})$$

$$a = (100)(0.20)$$

$$a = 20$$

Therefore:

$$c = \sqrt{a^2 + b^2}$$

$$c = 102$$

A reclaimed contour with a slope of 0.20 will have a 2% greater surface area than an acre which is flat. The percentage increase in surface area for various slopes can be found in Table 4.01, page 27.

The volume of topsoil salvaged and redistributed per acre also depends on the depth of topsoil which will be present after the topsoil has been redistributed. More topsoil must be redistributed than is present on the surface after redistribution because of spillage and the fact that part of the redistributed topsoil will sift down into the recontoured spoils. Approximately 70 to 90% of the topsoil salvaged will be present on the surface after topsoil redistribution,¹⁵ while approximately 10 to 30% of the topsoil redistributed will sift into the recontoured spoil banks (and be considered lost). If 4 inches of topsoil are desired on the reclaimed contour, and 80% of the topsoil salvaged is present after redistribution, 5 inches of topsoil must be salvaged and redistributed. (This is assuming the same general contour or slope before mining and after recontouring.)

Working through an example may be helpful in illustrating how the volume per acre of topsoil and the depth of topsoil which must be

¹⁵ Personal Interview, Reichmuth, Dr. Donald R., Associate Professor of Civil Engineering, Montana State University, Bozeman, Montana, January 1975.

Table 4.01

Conversion Factor for the Difference Between Horizontal
Area and Surface Area Relative to
Various Average Surface Slopes

Average Surface Slope	Increase in Surface Area from Horizontal Area (nearest 1/500)
0.00	0.000
0.05	0.000
0.10	0.005
0.15	0.010
0.20	0.020
0.25	0.030
0.30	0.045
0.35	0.060
0.40	0.075
0.50	0.120
0.60	0.165
0.70	0.220
0.80	0.280
0.90	0.345
1.00	0.415

salvaged can be found. Let us assume that:

0.25 = original contour slope

0.20 = reclaimed contour slope

4" = depth of topsoil present on recontoured spoil banks after topsoil redistribution

80% = the percentage of the redistributed topsoil present on the the recontoured mining area.

If 4" of topsoil are desired to be present after redistribution, then 5" of topsoil must be salvaged and redistributed ($4"/0.80 = 5"$).

If the reclaimed area was flat, then 5" times 4840 square yards (the area of an acre) 672.22 cubic yards per acre of topsoil are salvaged and redistributed. However, the reclaimed slope is 0.20 and not flat.

Referring to Table 4.01, the volume necessary to topsoil an acre with an average slope of 0.20 is 2% greater than that for a flat acre.

Therefore, the necessary volume to topsoil an acre is equal to $(1 + 0.02)$ (672.22 cubic yards) or 685.66 cubic yards. There must be 685.66 cubic yards of topsoil salvaged per acre to render 4" of topsoil on the reclaimed contour.

The depth of topsoil salvaged from the premining surface can also be found. Dividing the volume per acre of topsoil salvaged by the area of an acre and the increase in surface area because the premining area is not flat generates the depth of topsoil salvaged. In this example, the volume of topsoil salvaged equals 685.66 cubic yards, the area of an acre is 4840 yards, and the increase in surface area is 1.03 so the

depth of topsoil salvaged is 4.93 inches.

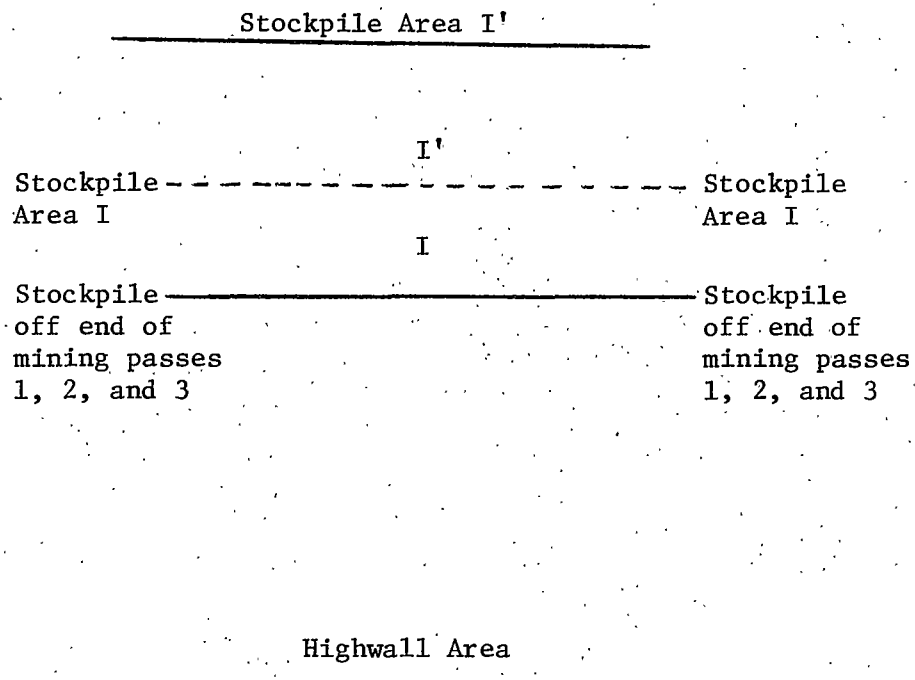
Method of Determining the Distance Topsoil is to be Moved

The distance the topsoil must be moved depends upon the mine design and the method of topsoil salvaging and redistribution. The method of topsoil salvaging and redistribution presented appears to minimize the amount of topsoil stockpiled, which would appear to minimize the cost of salvaging and redistributing topsoil. Stockpiling causes the loading and unloading of the topsoil twice, while direct transfer of the topsoil from salvaging to redistribution requires the topsoil to be loaded and unloaded only once. Loading and unloading is very time consuming relative to hauling and, therefore, is a major part of the topsoiling expense. If loading and unloading takes 1.2 minutes and hauling is done at 25 MPH, then the time spent loading and unloading to stockpile is equal to the time taken to haul the topsoil an extra 2640 feet or 1/2 mile. If stockpiling can be avoided by an extra haul distance (up to 1/2 mile), then stockpiling of topsoil should be avoided.

Before mining begins, the topsoil must be salvaged from the area where the initial spoil bank will be placed and adjacent areas to be mined, to allow for the recontouring of the initial spoil bank. For purposes of this study, it is assumed that salvaging the topsoil from where the first three mining passes will be made allows sufficient room for recontouring the initial spoil bank. The topsoil from the initial spoil bank area and the first three mining passes is stockpiled

off the edge of the initial spoil bank area and off the end of the first three mining passes, respectively.

Figure 4.02. Diagram of Area to be Topsoiled



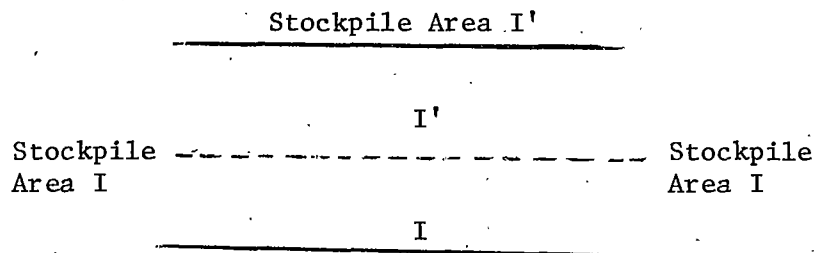
The topsoil from the 4th pass is directly redistributed on Area I. The remaining portion of the initial spoil bank area (referred to as area I') is topsoiled from the stockpiled topsoil from that area.

The topsoil from the 5th pass is moved directly to the recontoured 1st pass, the topsoil from the 6th pass to the 2nd pass, the 7th to the 3rd, etc. (The first pass is where the second spoil bank is located because the initial spoil bank is not a mining pass.)

The topsoil from the stockpiles off the end of area I and the first three mining passes is transported to and redistributed on or near the highwall area.

Since the method of topsoil salvaging and redistribution has been established, the distance the topsoil must be moved can be found. The topsoil stockpiled from area I' will be moved back to area I'.

Figure 4.03. Diagram of Topsoil Area in Initial Spoil Bank Area



Since the width of area I equals the width of a mining pass and Area I' and Area I' is the area between the initial highwall and the undisturbed area, the longest distance the topsoil is hauled is from area I' to the I' topsoil stockpile (the width of area I') and the shortest distance the topsoil must be transported is 0 (refer to Figure 4.03). The average haul distance is estimated as the average of the longest and shortest haul distance. (Machinery hourly production is generally computed relative to haul distance, so haul distance must be found.) Haul distance for redistributing the topsoil from the stockpile onto area A' is the same as for salvaging topsoil from area I'.

The topsoil from mining passes 1, 2, and 3 and area I is stock-

piled off the ends of the respective areas. The longest distance the topsoil must be transported is half the distance of the length of a mining pass or half the width of the mining area, while the shortest distance the topsoil must be transported is 0 to the stockpile. Therefore, the average haul distance is $1/4$ of the length of a mining pass.

The topsoil from mining pass 4 will be moved directly to Area I. The longest haul distance is equal to half the length of mining pass 4 plus the width of mining passes 4, 3, and 2 plus the width of Area I, plus half the length of area I. The shortest haul distance is the combined width of mining passes 1, 2, and 3. The average haul distance is the average of the longest and shortest haul distance. If the width and length of mining passes are uniform, the average haul distance is $(8 (\text{width of mining pass}) + \text{length of a mining pass})/2$. The average haul distance for direct distribution of topsoil salvaged from mining passes subsequent to mining pass 4 is equal to the average haul distance of topsoil salvaged from mining pass 4, if the length and width of mining passes are uniform.

The topsoil from the stockpiles off the end of mining passes 1, 2, and 3 and area I is redistributed on or near the highwall area. The longest haul distance is equal to the width of area to be topsoiled, (width of area to be mined plus the width of the additional area due to slope reduction of the highwall and the recontoured initial spoil bank) minus the width of area I' plus half the length of the highwall

area. The shortest haul distance is equal to the width of the mining area to be topsoiled minus the width of area I' minus the width of mining passes 1, 2, and 3 and area I, minus the width of the area where the topsoil is to be redistributed on or near the highwall area. The width of the area where the topsoil is to be redistributed (on or near the highwall area) is approximately equal to the width of mining passes 1, 2, and 3 and area I. Averaging the longest and shortest haul distance produces the average haul distance.

Chapter 5

Revegetation, Miscellaneous and Unallocated Cost

Estimation of Revegetation Cost

The next step in the reclamation process after topsoiling is revegetation. Revegetation should follow topsoiling as soon as possible to prevent soil erosion and to allow for maximum advantage for desirable species to become established. Even though revegetation is seasonal, revegetation should be accomplished at the first opportunity. ✓

The reclamation goals which will be considered are grazing, dryland crop, and various combinations of grassland and trees. Arbitrarily the planting of the first crop has been included in reclamation cost when reclaiming for dryland crop. Since winter wheat is the most prevalent dryland crop in the mining area, winter wheat will be used to represent the first dryland crop.

The cost of revegetating to dryland crop depends on (per acre basis):

- cost of winter wheat seed
- amount of winter wheat seeded per acre
- cost of fertilizer
- amount of fertilizer applied per acre
- machinery cost of seed bed preparation per acre (includes labor)
- machinery cost of seeding and fertilizing per acre (includes labor)
- machinery cost of fertilizing per acre (includes labor)

(Machinery costs are included for fertilizing and seeding and also for fertilizing because some fertilizer will be banded when seeding and some fertilizer will be broadcasted after seeding.)

The cost of revegetating for grazing depends on (per acre basis):

- plant seed mixture
- seed cost
- amount seeded per acre
- amount of fertilizer applied per acre
- cost of fertilizer
- machinery cost of seed bed preparation per acre (includes labor)
- machinery cost of fertilizing and seeding per acre (includes labor)
or aerial seeding
- machinery cost of fertilizing per acre (includes labor)

The cost of revegetation with a combination of grassland and trees depends on (per acre basis):

- cost of revegetation for grassland per acre (same as for grazing)
- cost of tree tublings or seedlings
- number of live trees desired per acre
- machinery cost of planting seedlings or tublings
- labor cost

Machinery costs are the same for grazing and cropland revegetation.

Farm machinery used to revegetate recontoured and topsoiled spoil banks incurs approximately four times the normal (for farming) repair expense and half the normal life of farm machinery. Also a higher powered tractor is required to pull machinery for revegetative purposes in reclaiming strip mined lands than is associated with normal farming practices.¹⁶

Machinery, with estimated sizes, used to revegetate for dryland crop and grazing include:

¹⁶ Personal Interview, Hodder, Richard L., Reclamation Research, Montana State University, Bozeman, Montana, December 1974.

tractor, 90 horsepower diesel
drill with fertilizer attachment, 12 foot
tractor, 55 horsepower gas
fertilizer spreader, 12 foot
tandem disc, 12 foot

Additional machinery used in revegetating for grassland and trees
include:

tractor, 40 horsepower gas
post-hole digger

The seedbed will be prepared with a small disc pulled by the 55 horsepower tractor. The 90 horsepower tractor pulls (at a faster than normal speed) for seeding and band fertilizing and the 55 horsepower tractor pulls the fertilizer spreader for broadcasting fertilizer. The post-hole digger is mounted on the 40 horsepower tractor for planting tublings.

Machinery costs for revegetating to dryland crop and grazing are estimated in Table 5.01.

Table 5.01. Machinery Cost Estimates for Dryland Crop and Grazing

	Cost/acre ¹⁷
Seedbed preparation	\$ 3.70
Seeding and band fertilizing	15.39
Broadcast fertilizing	<u>5.74</u>
Total	\$24.83

¹⁷ Explanation of cost determination may be found in Appendix B.

The amount of winter wheat seeded per acre is estimated at 40 lbs. If winter wheat seed costs \$6.00 per bushel, then the cost of winter wheat seed per acre is \$4.00.

A mixture of grass and shrub seed has been selected to be representative of seed mixtures used for revegetation to grazing and is presented in Table 5.02. (Grazing includes grazing for farm animals such as cattle, sheep, and horses, as well as wildlife such as deer, antelope, and various game birds.)

Table 5.02. Representative Revegetation Seed Mixture for Grazing¹⁸

<u>Grass or Shrub</u>	<u>lbs./acre</u>	<u>cost/lb.</u> ¹⁹	<u>cost/acre</u>
Western wheatgrass	2½	\$1.60	\$ 4.00
Slender wheatgrass	2½	0.68	1.70
Green needlegrass	2½	5.00	12.50
Orchard grass	1	0.65	0.65
Russian wildrye	1½	0.65	0.99
Yellow blossom sweetclover	1	0.35	0.35
Alfalfa (Ranger)	1	1.00	1.00
Cicer milkvetch	1	2.25	2.25
4-Wing saltbush	2	4.00	8.00
Greasewood	1	10.00	10.00
Total	16		\$41.44

The cost of the seed mixture applied at the rate of 16 lbs. per acre is estimated at \$41.44 per acre.

¹⁸Compiled by author and reviewed by Richard L. Hodder, Reclamation Research, Montana State University, Bozeman, Montana, February 1975.

¹⁹Seed prices received by telephone interview, Northrup King, Billings, Montana, February 1975.

Recent revegetation research indicates that generally a fertilization rate of 50 lbs. of available nitrogen and 75 lbs. of available phosphorus per acre is optimum for the first year.²⁰ Little or no response to potassium has been found.²¹ If 250 lbs. of 20-30-0 is applied per acre, then 50 lbs. of available nitrogen and 75 lbs. of available phosphorus will be provided per acre (phosphorus is in the form of P_2O_5). At \$242.40 per ton,²² the cost per acre of fertilizing is \$30.30.

It is assumed that no further additives are necessary for revegetation to grazing and cropland. However, the success of reclamation in part depends upon the long range management of strip mined lands, which may include further additives.²³ A cost summary of revegetation to cropland and grazing is presented in Table 5.03.

²⁰ Personal Communications, Hodder, Richard L., Reclamation Research, Montana State University, Bozeman, Montana, February, 1975.

²¹ Hodder, Richard L., Sindelar, Brian W., et al., "Coal Mine Land Reclamation Research", Research Report 30, Montana Agricultural Experiment Station, Montana State University, Bozeman, Montana, March 1972, p. 26.

²² Fertilizer prices received from Peavey Company, Miles City, Montana, February 1975.

²³ Reclamation Requirements May Not be Achievable, Billings Gazette, Billings, Montana, March 12, 1975, p. 10.

Table 5.03. Revegetation Cost Summary for Dryland Crop and Grazing.

<u>Revegetation Goal</u>	<u>Machinery Cost (including labor)</u>	<u>Seed</u>	<u>Fertilizer</u>	<u>Cost/acre</u>
Cropland	\$24.83	\$ 4.00	\$30.30	\$59.13
Grazing	24.83	41.44	30.30	96.57

Aerial seeding is an alternative seeding method. Aerial seeding costs approximately \$1 per acre²⁴ and requires about twice as much seed applied per acre as seeding done with farm machinery to obtain the same results. It is assumed that all fertilizer will be broadcasted with a fertilizer spreader, and will be applied at the same rate as previously assumed. Table 5.04 presents a cost summary of both aerial seeding and seeding with farm machinery.

Table 5.04. Revegetation Cost Summary for Grazing (Aerial and Farm Machinery Seeding).

<u>Seeding Method</u>	<u>Machinery Cost (including labor)</u>	<u>Seed</u>	<u>Fertilizer</u>	<u>Cost/acre</u>
Aerial	\$10.44	\$82.88	\$30.30	\$123.62
Farm Machinery	24.83	41.44	30.30	96.57

Aerial seeding is more expensive than seeding with farm machinery. If aerial seeding and seeding with farm machinery produce equal

²⁴Personal Communications, Choate, Lyman, Aerial Sprayer and Seeder, Miles City, Montana, April 1975.

revegetation results, it would appear that seeding with farm machinery would be preferred, all else being equal.

Trees may be planted at various stages of growth and therefore various machinery costs may be incurred along with various survival rates. Three-foot tublings with 2 foot of root growth and seedlings 7 to 10 inches tall will be considered. The tublings will be considered with and without plastic aprons. (Plastic aprons are black pieces of plastic cut in 6 foot diameter circles, split to the center so that the plastic can be placed around the base of a tree in such a way that the base of the tree is in the center of the plastic circle. The plastic is held in place by soil placed around the outer edge of the circle. The function of the plastic apron is to increase soil temperature and conserve soil moisture in the root area.)

Table 5.05. Cost of Planting a Tree.

Stage of Tree Growth	Tree ²⁵		Machinery ²⁷ Cost	Total Cost	Survival ²⁸ Rate	Cost/Live Tree
	Cost	Labor ²⁶				
Tubling (without Plastic Aprons)	\$1.00	\$0.33	\$0.64	\$1.97	0.7	\$2.81
Tubling (with Plastic Aprons)	\$1.50	1.00	0.64	3.14	0.9	3.38
Seedling	0.20	0.20	0.00	0.40	0.4	1.00

²⁵ Personal communications, Hodder, Richard L., Reclamation Research, Montana State University, Bozeman, Montana, February, 1975.

²⁶ Labor valued at \$4.00 per hour.

The cost per acre of revegetation to grassland and trees may be estimated by adding the cost for revegetating to grazing (Table 5.04) and the cost per tree (Table 5.05) times the number of trees desired.

Miscellaneous and Unallocated Costs

Miscellaneous and unallocated costs cover a variety of costs. Miscellaneous costs vary widely due to the organization of the mining company, state and local laws, mine design, and reclamation goal. Miscellaneous and unallocated costs cover overhead expense, taxes, bond expense, engineering expense, repair drainage systems, special wildlife habitat (buck brush, rock piles, etc.), miscellaneous machinery expense (i.e. trucks for hauling seed, fertilizer, and seedlings or tublings) and additional topsoiling costs due to less than optimum topsoiling conditions. For purposes of cost estimation for reclamation, miscellaneous and unallocated costs are estimated at \$100 per acre.²⁹ If the miscellaneous and unallocated cost estimate is accurate for the reclamation goals of cropland and grazing, then the estimate is understated when trees are planted.

Before closing this section, the author would like to impress upon

²⁷ Explanation of cost determination may be found in Appendix B.

²⁸ Personal Communications, Hodder, Richard L., Reclamation Research, Montana State University, Bozeman, Montana, February 1975.

²⁹ Estimated in a personal interview by Tom Gwyn, Public Relations, Knife River Coal Company, October, 1974.

the reader that this is not a biological study but a simulation and an analysis of reclamation cost when the presented methods are followed.

The degree of acceptability of reclamation produced by the presented methods is not judged by the author.

Chapter Six

Reclamation Cost Examples

This chapter will use methods and procedures presented in previous chapters to produce some reclamation cost estimates. The assumed characteristics of the mining area are presented on page 56. Machinery cost estimates are presented in Tables 6.01 and 6.02.

One example of cost generation will be worked through for illustrative purposes. The remaining reclamation estimates (which follow this chapter) have been produced using the same methods. The example which will be worked through is on Table 6.03, page 57.

Generation of Recontouring Cost

The yardage per acre moved in recontouring is found as described in Chapter Three for the various areas. The cost per yard moved depends upon the distance the volume is moved as well as the volume of overburden moved. The average distance the volume is to be moved is estimated by averaging the longest and shortest distance the volume is to be moved.

In the initial spoil bank (ISB) area the bulldozer will push from the peak of the ISB both directions. The longest push on the ISB side distal to the undisturbed area is $\frac{C + H1}{RS}$ (refer to Figure A.04) or in this example $\frac{0.64 \text{ yards} + 3.32 \text{ yards}}{0.05} = 79.2 \text{ yards}$. The shortest push distance is the minimum of 50 feet. The average push distance on the distal side of the ISB is $(79.2 \text{ yards})(3 \text{ feet}) + 50 \text{ feet})/2 = 143.8 \text{ feet}$.

The longest push on the side of the ISB proximal to the undisturbed area is $\frac{H1}{RS}$ (refer to Figure A.04) or in this example $\frac{3.32 \text{ yards}}{0.05} = 66.4$ yards. The shortest push distance is the minimum of 50 feet. The average push distance on the proximal side of the ISB is $((66.4 \text{ yards}) (3 \text{ feet}) + 50 \text{ feet})/2 = 119.6 \text{ feet}$. Averaging the push distance on the proximal and distal side of the ISB, $\frac{143.8 \text{ feet} + 119.6 \text{ feet}}{2} = 131.7 \text{ feet}$, which estimates the average push distance in the ISB area. Extrapolating from Table 6.01, page 54 the cost per yard moved is \$0.054.

The longest push distance on the highwall side of the highwall area is equal to Y where:

$$Y = ((RSO)(X) + C)/(RSW + RSO)$$

(derivation may be found in Appendix C)

RSO = reclaimed slope opposite highwall

RSW = reclaimed highwall slope

$$X = \text{total highwall area width or } \frac{D - DP}{RSW} - \frac{D - DP}{HS} + LE$$

(refer to Figures A.08 and A.10, LE is determined in the model for estimating spoils moved on the spoil bank side of the highwall area, Appendix A)

C = highwall height minus average spoil bank height

or in this example

$$X = \frac{7.04 \text{ yards} - 4.38 \text{ yards}}{0.05} - \frac{7.04 \text{ yards} - 4.38 \text{ yards}}{3} + 78.35$$

yards = 130.66 yards

$$Y = ((0.05)(130.66 \text{ yards}) + 0.64)/(0.20 + 0.05)$$

= 28.69 yards or 86.07 feet

The shortest push distance is the minimum of 50 feet. The average push distance is $\frac{50 \text{ feet} + 86.07 \text{ feet}}{2} = 68.04 \text{ feet}$. The cost per yard moved is \$0.043 since the average push distance is less than 100 feet (refer to Table 6.01, page 54). Ripping cost of \$0.029 must be added to the moving cost of \$0.043 for a total cost per yard moved of \$0.072.

The longest push to recontour the slope opposite the highwall (slope RSO, Figure A.10) is equal to LE or 78.35 yards. The shortest push distance is the minimum push distance of 50 feet. Therefore, the average push distance is 142.25 feet. Extrapolating from Table 6.01, page 54, the cost per yard moved is \$0.057.

In recontouring ramp roads, the longest push distance equals $\frac{W'}{2} + S$ where $X = \frac{((4)(\text{Area } 4))}{OS} \cdot \frac{1}{2}$ (derivation may be found in Appendix C) or in this example $\frac{26 \text{ yards}}{2} + 16.97 \text{ yards} = 29.97 \text{ yards or } 89.91 \text{ feet}$. The shortest push distance is the minimum of 50 feet and the average push distance is 69.96 feet. Since the average push distance is less than 100 feet the cost per yard moved is \$0.043 (refer to Table 6.01, page 54).

The longest push distance in the remaining spoil bank area is determined by the pit width. If the bulldozer pushes from the spoil bank peak to the spoil bank vee, the longest push distance equals half the distance between spoil bank peaks or half the mining pit width. The shortest push distance is the minimum push distance of 50 feet. The

assumed pit width is 40 yards, therefore the average push distance is 55 feet and the cost per yard moved is \$0.043 (from Table 6.01, page 54).

Multiplying the yardage per acre moved times the cost per yard moved estimates recontouring cost per acre for various areas.

The number of acres in each area included in the 1000 acres mined may be found. In the ISB and highwall area, the acreage may be estimated by dividing the variable labeled ACRE relative to the appropriate area (refer to Appendix A) by the length of the ISB or highwall. Acres included in the ISB area equal $4840 \text{ yards} / 78.84 \text{ yards}$ or 61.38 acres and acres included in the highwall area equal $4840 \text{ yards} / 44.60 \text{ yards}$ or 108.52 acres.

The number of acres included in the ramp roads depends upon the length of the ramp road. The length of the ramp road is equal to the width of the mining area (1000 yards) minus the final pit width (40 yards) plus the width of the ISB base (35.78 yards, refer to Appendix A) divided by the ramp road width equals the acres in a ramp road. The acres included in a ramp road are $995.78 \text{ yards} / 186.15 \text{ yards}$ or 5.35 acres. The 10 ramp roads present in the example include 53.50 acres of ramp road.

The remaining spoil bank acreage may be found by subtracting the ISB and highwall area in the example from the total acreage mined. The remaining spoil bank acreage equals $1000 - 61.38 - 108.52$ or 830.10 acres.

Multiplying the cost per acre times the number of acres yields the overburden manipulation or recontouring cost in each area. Totaling the cost of each area renders a total cost estimate of overburden manipulation.

Topsoiling Cost

To find the volume of topsoil to be salvaged, the volume of topsoil to be redistributed must be determined. The volume of topsoil to be salvaged and redistributed depends upon the depth of topsoil desired on reclaimed land, slope of reclaimed land, and the acreage to be topsoiled.

The acreage to be topsoiled is greater than the area mined because of slope reduction in the highwall area and placing of the ISB outside the area to be mined.

If the width of the highwall area is known, the acreage included in the highwall area can be found. The width of the highwall area is equal to X where:

$$X = \frac{D - D'}{RSW} - \frac{D - D'}{HS} + LE \text{ (refer to Figure A.10, Appendix A)}$$

In this example, X equals 130.66 yards. The acreage in the highwall area equals (length of highwall) / $\frac{(\text{area of an acre})}{X}$ or in this example (4840 yards) / $\frac{(4840 \text{ square yards})}{130.6 \text{ yards}} = 130.66 \text{ acres}$.

Since the recontoured slope on the highwall side differs from the recontoured slope opposite the highwall and therefore the volume of topsoil redistributed per acre necessary to provide for same topsoil depth is different, the area of both slopes must be found. The width

of the slope on the highwall side is Y where:

$$Y = ((RSO)(S) + C) / (RSW + RSO)$$

(derivation may be found in Appendix C)

RSO = reclaimed slope opposite highwall
RSW = reclaimed highwall slope
X = highwall area width
C = highwall height - average spoil bank height

$$Y = ((0.05)(130.06) + 0.64) / (0.20 + 0.05)$$
$$= 28.69 \text{ yards}$$

The acreage in the recontoured highwall slope is equal to
(length of highwall) / $\frac{(\text{area of an acre})}{Y}$ or in this example
(4840 yards) / $\frac{(4840 \text{ square yards})}{28.69}$ = 28.69 acres.

The acreage in the slope opposite the highwall is equal to the total acreage in the highwall area minus the acreage in the recontoured highwall slope. In this example, the slope opposite the highwall is equal to 130.66 acres minus 28.69 acres or 101.97 acres.

The acreage to be topsoiled in the ISB area may be found if the width of the area is known. The width of the area to be topsoiled is equal to $L + \frac{1}{2} \text{ base of the ISB} + H1/RS$ (refer to Appendix C). In this example, the width is 61.38 yards + 38.78 yards/2 + 3.23 yards/0.05 or 143.87 yards. The acreage in the ISB area to be topsoiled is equal to
(length of ISB) / $\frac{(\text{area of an acre})}{\text{width of ISB area}}$ or in this example
(4840 yards) / $\frac{(4840 \text{ square yards})}{183.37 \text{ yards}}$ = 143.87 acres.

The remaining area is equal to the total acres mined minus ISB acreage mined minus the highwall acreage mined. In this example, the remaining acreage equals 1000 - 61.39 - 108.52 - 830.10 acres.

As found in Chapter Four, the volume of topsoil necessary to

topsoil a flat acre 4 inches deep is 672.22 cubic yards.

The yardage to be redistributed in each area equals the acres times the conversion factor³⁰ plus one times the yardage necessary to topsoil a flat acre. Total acreage and yardage can be found by totaling the appropriate column. The average volume per acre of topsoil to be redistributed equals the total volume of topsoil divided by the acres to be topsoiled or 742,940.09 cubic yards divided by 1,104.63 acres or 672.57 cubic yards per acre.

The topsoil from the first three mining passes and a portion of the ISB area is stockpiled and then redistributed on or near the highwall area. As explained in Chapter Four, the topsoil from area I' will be stockpiled off the edge of area I' and the topsoil from mining passes 1, 2, and 3 and a portion of the ISB area will be stockpiled off the end of the respective areas. The remaining area will be topsoiled by direct distribution (salvaging and redistribution topsoil without stockpiling).

If the width of I' is known, the acreage included in area I' can be found. The portion of the ISB area included with the first three mining passes is equal to the width of a mining pass. The width of the area between the initial highwall and the undisturbed area is equal to $\frac{B}{2} + \frac{H1}{RS}$ (refer to Figure A.04) or in this example $\frac{35.78 \text{ yards}}{2}$.

³⁰The conversion factor is used if the area to be topsoiled is not flat as explained in Chapter Four. Conversion factors may be found in Table 4.01.

+ $\frac{3.32 \text{ yards}}{84.29 \text{ yards}}$, Subtracting the width of a mining pass from the width between the initial highwall and the undisturbed area or 84.29 yards minus the 40 yards or 44.29 yards is the width of area I'. The total acreage in area I' equals

$$\frac{(\text{length of ISB}) \times (\text{area of an acre})}{\text{width of area I'}} \text{ or in this example}$$
$$(4840 \text{ yards}) / \frac{(4840 \text{ square yards})}{44.29 \text{ yards}} = 44.29 \text{ acres.}$$

The width of the first three mining passes plus a portion of the ISB area is equal to four times the width of mining pass or in this example, 160 yards. The acreage included in the first three mining passes and a portion of the ISB area is

$$\frac{(\text{length of the mining acre}) \times (\text{area of an acre})}{\text{width of 4 mining passes}} \text{ or in this example, } (4840 \text{ yards}) / \frac{(4840 \text{ square yards})}{160 \text{ yards}} = 160 \text{ acres.}$$

The acreage which is to be topsoiled by direct distribution is equal to the total acreage to be topsoiled minus the acreage in area I' minus the acreage in 4 mining passes or in this example, 1104.63 acres - 44.29 acres - 160 acres = 900.29 acres.

The average yardage moved per acre is approximately the same as the average yardage per acre salvaged or in this example, 672.57 cubic yards per acre. Multiplying the yardage moved per acre times the number of acres topsoiled produces the volume moved for each area.

The cost per yard of moving the topsoil depends on the haul distance. Haul distance will be estimated by averaging the longest and shortest haul distance. In area I' the longest haul distance to the

stockpile is equal to the width of area I' or 44.29 yards or 132.87 feet. Since the longest haul distance is less than 500 feet (refer to Table 6.02, page 55) the average haul distance is less than 500 feet and the cost per yard is \$0.025.

The longest haul distance off the end of the first three mining passes and a portion of the ISB area is equal to half the length of a mining pass. The shortest haul distance is nearly 0 and will be considered 0 for the purposes of this study. Therefore, the average haul distance is one-fourth of the length of a mining pass or in this example, $\frac{4840 \text{ yards}}{4} = 1210 \text{ yards or } 3630 \text{ feet}$. Extrapolating from Table 6.02, page 55 cost per yard is \$0.432.

When salvaging and redistributing topsoil without stockpiling or directly distributing the topsoil, the longest haul is equal to the width of 4 mining passes plus the length of a mining pass or in this example, $5(40 \text{ yards}) + 4840 \text{ yards} = 5040 \text{ yards}$. The shortest haul distance equals the width of three mining passes or in this example, $3(40 \text{ yards}) = 120 \text{ yards}$. The average haul distance is $\frac{5040 \text{ yards} + 120 \text{ yards}}{2} = 2580 \text{ yards or } 7740 \text{ feet}$. Extrapolating from Table 6.02, page 55, the cost per yard is \$0.693.

The longest haul distance from the topsoil stockpiles off the end of the first three mining passes and a portion of the ISB area to redistribute on or near the highwall area is equal to the width of the mining area to be topsoiled minus the width of area I' plus half the

length of a mining pass. The width of the mining area topsoiled equals
$$\frac{(\text{total acreage to be topsoiled})(\text{area of an acre in square yards})}{\text{length of the mining area}}$$

or in this example,

$$\frac{(1104.63 \text{ acres})(4840 \text{ square yards})}{4840 \text{ yards}} = 1104.63 \text{ yards.}$$
 The longest haul distance is equal to 1104.63 yards - 44.29 yards + $\frac{4840 \text{ yards}}{2} = 3480.34$ yards. The shortest haul distance is equal to the width of the area to be topsoiled minus the width of 8 mining passes minus the width of area I' or in this example, 1104.63 yards - 44.29 yards - 8(40 yards) = 730.34 yards. The average haul distance is 2110.34 yards or 6331.02 feet. Extrapolating from Table 6.02, page 55, the cost per yard is \$0.603.

Multiplying the cost per yard times the yardage equals the cost of topsoiling. Totaling the column labeled cost renders an approximation of the total cost of topsoiling.

Generation of Revegetation, Miscellaneous, and Unallocated Costs

Revegetation cost equals the number of acres to be revegetated (same as the number of acres to be topsoiled) times the cost per acre of revegetation.³¹ In this example, the revegetation goal is grazing. Per acre revegetation cost is \$96.57 and the number of acres revegetated is 1,104.63 acres. Total revegetation costs are estimated at \$196,674.11

³¹ Revegetation cost estimates for various reclamation goals are presented in Chapter Four.

in this example. Miscellaneous and unallocated costs are estimated by multiplying the cost per acre times the number of acres revegetated or topsoiled.

Totaling the costs of overburden manipulation, topsoiling, revegetating, and miscellaneous and unallocated cost estimates the total reclamation costs.

The reader should note that sometimes during the mining process the spoil banks may be partially leveled. If this is the case, the cost of leveling done for purposes of mining should not be allocated to reclamation costs.

Table 6.01

Machinery Cost for Overburden Manipulation

Push Distance (feet)	Cost/yard ¹ (dollars)
100 ²	0.043
150	0.060
200	0.077
250	0.093
300	0.108
350	0.124
400	0.141
450	0.159
500	0.176
550	0.192
600	0.210
650	0.221

Minimum push distance is 50 feet.

Assumptions:

Equipment: D9 caterpillar tract-type tractor with universal blade.
Hourly operating costs at \$42.74 per hour.³

Labor: valued at \$8.00 per hour.

Efficiency: 85%

¹Derived from the Caterpillar Performance Handbook, fifth ed., 1975, Section 4, page 21.

²Push distance of less than 50 feet is assumed to incur the same cost as a 50 foot push.

³Caterpillar Performance Handbook, fifth ed., 1975, Section 28, page 38.

Machinery Cost for Ripping

Ripping Cost: 0.029 per cubic yard⁴

Assumptions:

Equipment: D9 caterpillar track-type tractor with a tandem
ripper. Hourly operating costs at \$42.74 per hour.

Efficiency: 85%

⁴Derived from Caterpillar Performance Handbook, fifth ed., 1975, Section 6.

Table 6.02

Machinery Cost for Topsoiling

Haul Distance (feet)	Cost/yard ¹ (dollars)
500 ²	0.225
1000	0.264
1500	0.296
2000	0.329
2500	0.360
3000	0.392
3500	0.424
4000	0.455
4500	0.487
5000	0.519
6000	0.582
7000	0.646
8000	0.710

Assumptions:

Equipment: 657 Push-pull wheel tractor scraper. Hourly operating costs at \$164.10 per hour.

Labor: valued at \$8.00 per hour.

Load factor: 0.80

¹Derived from the Caterpillar Performance Handbook, fifth ed., 1975, Section 11, pages 14, 52, 53.

²Haul distance of less than 500 feet is assumed to incur the same cost as a 500 foot haul.

³Caterpillar Performance Handbook, fifth ed., 1975, Section 28, page 39.

Assumptions for Cost Examples

Area mined contains 1000 acres, 4840 yards long and 1000 yards wide. Highwall and initial spoil bank are 4840 yards long. Ramp roads are spaced one quarter of a mile apart and ten are present on the mining area. The swell factor is 0.25. The overburden thickness is uniform throughout the area. The term topsoil in these examples is the specified inches of soil on the surface prior to mining, which may or may not be scientifically topsoil. Topsoil depth after reclamation is 4 inches unless otherwise stated. The highwall slope is three and the spoil bank slope is 0.8. The mining pit width or the distance between spoil bank peaks is 40 yards. The ramp road width is 10 yards. The area before mining has a 10% slope. Seeding is assumed to be done with farm machinery.

Table 6.03

Cost Summary

Reclamation goal: grazing; Topsoil depth: 4"; Highwall height: 7.04 yards;
Overburden depth: 5.12 yards; Reclaimed highwall slope: 20%; Initial spoil
bank and reclaimed slope opposite highwall: 5%; All other reclaimed slopes: 0%.

Recontouring Cost Summary

Area	Yardage/acre moved	Cost/yard moved	Cost per acre	Acres	Cost
Initial spoil bank	11,979.2	\$0.054	\$646.88	61.38	\$39,705.49
Highwall (highwall side)	738.5	0.072	53.17	108.52	5,770.01
(spoil bank side)	4,024.4	0.057	229.39	108.52	24,893.40
Ramp road	21,444.9	0.043	922.13	53.50	49,333.96
Remaining spoil banks	9,680.0	0.043	416.24	830.10	345,520.82
Total overburden cost					\$465,223.68

Topsoil to be Redistributed

Area	Acres	Conversion factor + 1	Flat Acre	Total Yardage
Initial spoil bank	143.87	1.000	672.22	96,712.29
Highwall (highwall side)	28.69	1.020	672.22	19,671.71
(spoil bank side)	101.97	1.000	672.22	68,546.27
Remaining spoil banks	830.10	1.000	672.22	558,009.82
Total acres topsoiled	1,104.63		Total yardage	742,940.09

672.57 yards of topsoil are salvaged per acre.

Topsoil Cost Summary

Area	Acres	Average Yardage/acre	Yardage	Cost Yard	Cost
Stockpiling (area I')	44.29	672.57	29,788.13	\$0.225	\$6,702.33
(1,2,3 & ISB)	160.00	672.57	107,611.20	0.432	46,488.04
Direct distribution	900.34	672.57	605,541.67	0.693	419,640.37
Redistribution (area I')	44.29	672.57	29,788.13	0.225	6,702.33
(Highwall proximity)	160.00	672.57	107,611.20	0.603	64,889.55
Total topsoiling cost					\$544,422.62

Revegetation Cost

1,104.63 acres times \$96.57 per acre = \$106,674.11

Miscellaneous and Unallocated Costs

1104.63 acres times \$100.00 per acre = \$110,463.00

Total Cost Summary

Recontouring	\$465,223.68
Topsoiling	544,422.62
Revegetation	106,674.11
Miscellaneous and unallocated costs	110,463.00
Total cost	\$1,226,783.41

Cost per acre mined is \$1,226.78

Table 6.04
Cost Summary

Reclamation goal: grazing; Topsoil depth: 4"; Highwall height: 7.04 yards;
Overburden depth: 5.16 yards; Reclaimed highwall slope: 20%; All other
reclaimed slopes: 0%.

Recontouring Cost Summary

Area	Yardage/acre moved	Cost/yard moved	Cost per acre	Acres	Cost
Initial spoil bank	11,979.2	\$0.054	\$646.88	61.38	\$39,705.49
Highwall (highwall side)	738.5	0.072	53.17	108.52	5,770.01
(spoil bank side)	4,024.4	0.073	293.78	108.52	31,881.01
Ramp road	19,871.5	0.043	854.47	53.50	45,714.15
Remaining spoil banks	9,075.0	0.043	390.23	830.10	323,929.92
Total overburden costs					\$447,000.58

Topsoil to be Redistributed

Area	Acres	Conversion factor + 1	Flat acre	Total yardage
Initial spoil bank	143.87	1.000	672.22	96,712.29
Highwall (highwall side)	28.69	1.020	672.22	19,671.71
(spoil bank side)	101.97	1.000	672.22	68,546.27
Remaining spoil banks	830.10	1.000	672.22	558,009.82
Total acres topsoiled	1,104.63		Total yardage	742,490.09

672.57 yards of topsoil are salvaged per acre.

Topsoil Cost Summary

Area	Acres	Average Yardage/acre	Yardage	Cost Yard	Cost
Stockpiling (area I')	44.29	672.57	29,788.13	\$0.225	\$6,702.33
(1,2,3 & ISB)	160.00	672.57	107,611.20	0.432	46,488.04
Direct distribution	900.34	672.57	605,541.67	0.693	419,640.37
Redistribution (area I')	44.29	672.57	29,788.13	0.225	6,702.33
(highwall proximity)	160.00	672.57	107,611.20	0.603	64,889.55
Total topsoiling cost					\$544,422.62

Revegetation Cost

1,104.63 acres times \$96.57 per acre = \$106,674.11

Miscellaneous and Unallocated Costs

1104.63 acres times \$100.00 per acre = \$110,463.00

Total Cost Summary

Recontouring	\$447,000.58
Topsoiling	544,422.62
Revegetation	106,674.11
Miscellaneous and unallocated costs	110,463.00
Total cost	\$1,208,560.31
Cost per acre mined is	\$1,208.56

Table 6.05
Cost Summary

Reclamation goal: grazing; Topsoil depth: 4"; Highwall height: 7.04 yards;
Overburden depth: 5.12 yards; Reclaimed highwall slope: 20%; All other
reclaimed slopes: 10%.

Recontouring Cost Summary

Area	Yardage/acre moved	Cost/yard moved	Cost per acre	Acres	Cost
Initial spoil bank	15,671.5	\$0.044	\$689.55	36.94	\$25,471.98
Highwall (highwall side)	1,296.9	0.072	93.38	78.35	7,316.32
(spoil bank side)	2,767.6	0.057	157.75	78.35	12,359.71
Ramp road	18,298.5	0.043	786.84	53.50	42,095.94
Remaining spoil banks	8,470.0	0.043	364.21	884.71	322,220.22
Total overburden cost					\$409,464.17

Topsoil to be Redistributed

Area	Acres	Conversion factor + 1	Flat acre	Total yardage
Initial spoil bank	103.20	1.005	672.22	69,719.97
Highwall (highwall side)	30.25	1.020	672.22	20,741.35
(spoil bank side)	54.00	1.005	672.22	36,481.38
Remaining spoil banks	884.71	1.005	672.22	597,693.35
Total acres topsoiled	1,072.16		Total yards salvaged	724,636.05

675.87 yards of topsoil must be salvaged per acre disturbed.

Topsoil Cost Summary

Area	Acres	Average yardage/acre	Yardage	Cost yard	Cost
Stockpiling (area I')	26.26	675.87	17,748.35	\$0.225	\$3,993.38
Portion ISB area of	160.00	675.87	108,139.20	0.432	46,716.13
Mining passes 1,2,3					
Remaining area	885.90	675.87	598,753.23	0.693	414,935.98
Redistribution (area I')	26.26	675.87	17,748.35	0.225	3,993.38
(highwall proximity)	160.00	675.57	108,139.20	0.600	64,883.52
Total topsoiling cost					\$534,522.39

Revegetation Cost

1,072.16 acres times \$96.57 per acre = \$103,538.49

Miscellaneous and Unallocated Costs

1,072.16 acres times \$100 per acre = \$107,216.00

Total Cost Summary

Recontouring	\$409,464.17
Topsoiling	534,522.39
Revegetation	103,538.49
Miscellaneous and unallocated costs	107,216.00
Total cost	\$1,154,741.05

Cost per acre mined is \$1,154.74

Table 6.06
Cost Summary

Reclamation goal: grazing; Topsoil depth: 4"; Highwall height: 7.04 yards;
Overburden depth: 5.12 yards; All reclaimed slopes: 5%.

Recontouring Cost Summary

Area	Yardage/acre moved	Cost/yard moved	Cost per acre	Acres	Cost
Initial spoil bank	11,979.2	\$0.055	\$658.86	61.5	\$40,519.89
Highwall (highwall side)	2,367.2	0.060	142.03	108.5	15,410.26
(spoil bank side)	4,024.4	0.073	293.78	108.5	31,875.13
Ramp road	21,444.9	0.043	922.13	53.5	49,333.96
Remaining spoil banks	9,075.0	0.043	390.23	830.0	323,890.90
Total overburden cost					\$461,030.14

Topsoil to be Redistributed

(Since all acreage is reclaimed to some slope, if total acreage is known, conversion factor can be applied to all acres.)

Area	Acres	Conversion Factor + 1	Flat acre	Total yardage
Initial spoil bank	145.77			
Highwall	155.1	1.00	672.22	759,857.32
Remaining spoil banks	830.0			
Total acres topsoiled	1,130.37			

Average yardage per acre 672.22

Topsoil Cost Summary

Area	Acres	Average yardage/acre	Yardage	Cost yard	Cost
Stockpiling (area I')	44.27	672.22	25,759.18	\$0.225	\$6,695.82
(1,2,3 & ISB)	160.00	672.22	107,555.20	0.432	46,463.85
Direct distribution	926.10	672.22	622,542.94	0.693	431,422.25
Redistribution (Area I')	44.27	672.22	29,759.18	0.225	6,695.82
(highwall proximity)	160.00	672.22	107,555.20	0.608	65,393.56
Total topsoiling cost					\$556,671.30

Revegetation Cost

1,130.37 acres times \$96.57 per acre = \$109,159.83.

Miscellaneous and Unallocated Costs

1,130.37 acres times \$100 per acre = \$113,037.00.

Total Cost Summary

Recontouring	\$461,030.14
Topsoiling	556,671.30
Revegetation	109,159.83
Miscellaneous and unallocated costs	113,037.00
Total cost	\$1,239,898.27

Cost per acre mined is \$1,239.90.

Table 6.07

Cost Summary

Reclamation goal: grazing; Topsoil depth: 4"; Highwall height: 7.04 yards;
Overburden depth: 5.12 yards; All reclaimed slopes: 10%.

Recontouring Cost Summary					
<u>Area</u>	<u>Yardage/acre moved</u>	<u>Cost/yard moved</u>	<u>Cost per acre</u>	<u>Acres</u>	<u>Cost</u>
Initial spoil bank	15,671.5	\$0.044	\$ 689.50	36.04	\$ 25,471.98
Highwall (highwall side)	2,266.2	0.046	104.25	78.35	8,167.99
(spoil bank side)	2,767.6	0.057	157.75	78.35	12,359.71
Ramp road	18,298.5	0.043	786.84	53.50	42,095.94
Remaining spoil banks	8,470.0	0.043	364.21	884.71	322,220.22
Total overburden cost					\$410,315.84

Topsoil to be Redistributed				
<u>Area</u>	<u>Acres</u>	<u>Conversion Factor + 1</u>	<u>Flat acre</u>	<u>Total yardage</u>
Initial spoil bank	103.2			
Highwall	105.85	1.005	672.22	738,923.58
Remaining spoil banks	884.71			
Total acres topsoiled	1,093.76			

675.58 yards of topsoil are salvaged per acre.

Topsoil Cost Summary					
<u>Area</u>	<u>Acres</u>	<u>Average yardage/acre</u>	<u>Yardage</u>	<u>Cost yard</u>	<u>Cost</u>
Stockpiling (area I')	26.26	675.58	17,740.73	\$0.225	\$3,991.66
(1,2,3, & ISB)	160.00	675.58	108,092.80	0.432	46,696.09
Direct distribution	907.50	675.58	613,088.85	0.603	424,870.57
Redistribution (area I')	26.26	675.58	17,740.73	0.225	3,991.66
(highwall proximity)	160.00	675.58	108,092.80	0.605	65,396.14
Total topsoiling cost					\$544,946.12

Revegetation Cost

1,093.76 acres times \$96.57 per acre = \$105,624.40.

Miscellaneous and Unallocated Costs

1,093.76 acres times \$100.00 per acre = \$109,376.00.

Total Cost Summary

Recontouring	\$410,315.84
Topsoiling	544,946.12
Revegetation	105,624.40
Miscellaneous and unallocated costs	109,376.00
Total cost	\$1,170,262.36

Cost per acre mined is \$1,170.26.

Table 6.08

Cost Summary

Reclamation goal: grazing; Topsoil depth: 4"; Highwall height: 7.04 yards;
Overburden depth: 5.12 yards; All reclaimed slopes: 20%.

Recontouring Cost Summary

Area	Yardage/acre moved	Cost/yard moved	Cost per acre	Acres	Cost
Initial spoil bank	20,717.9	\$0.043	\$890.87	20.25	\$18,040.12
Highwall (highwall side)	1,401.5	0.072	100.91	62.35	6,291.74
(spoil bank side)	1,490.5	0.049	73.03	62.35	4,553.42
Ramp road	15,766.91	0.043	677.98	53.50	36,271.93
Remaining spoil banks	7,260.0	0.043	312.81	917.40	286,393.93
Total overburden cost					\$351,551.14

Topsoil to be Redistributed

Area	Acres	Conversion Factor +1	Flat Acre	Total yardage
Initial spoil bank	73.07	1.02	672.22	50,101.50
Highwall (highwall side)	39.73	1.02	672.22	27,241.45
(spoil bank side)	22.63	1.02	672.22	15,516.59
Remaining spoil banks	917.40	1.02	672.22	629,028.52
Total acres topsoiled	1,052.83	Total yards salvaged		721,888.06

685.66 yards of topsoil must be salvaged per acre.

Topsoil Cost Summary

Area	Acres	Average Yardage/acre	Yardage	Cost yard	Cost
Stockpiling (area I')	12.82	685.66	8,790.16	\$0.225	\$1,997.79
Stockpiling ISB area and mining passes 1, 2, & 3	160.00	685.66	109,705.60	0.432	47,392.82
Direct distribution	880.01	685.66	603,387.65	0.693	418,147.64
Redistribution (area I')	12.82	685.66	10,970.60	0.225	47,392.82
(highwall proximity)	160.00	685.66	8,790.16	0.483	1,997.79
Total topsoiling cost					\$516,888.86

Revegetation Cost

1,052.83 acres times \$96.57 per acre = \$101,671.79.

Miscellaneous and Unallocated Costs

1,052.83 acres times \$100.00 per acre = \$105,283.00

Total Cost Summary

Recontouring	\$351,551.14
Topsoiling	516,888.86
Revegetation	101,671.79
Miscellaneous and unallocated costs	105,283.00
Total cost	\$1,075,394.79

Cost per acre mined is \$1,075.39.

Table 6.09
Cost Summary

Reclamation goal: grazing; Topsoil depth: 4"; Highwall height: 7.04 yards;
Overburden depth: 5.12 yards; Reclaimed highwall slope: 35%; All reclaimed
slopes: 5%.

Recontouring Cost Summary					
Area	Yardage/acre moved	Cost/yard moved	Cost acre	Acres	Cost
Initial spoil bank	11,979.2	\$0.054	\$646.88	61.38	\$39,705.49
Highwall (highwall side)	419.5	0.072	30.20	108.52	3,277.30
(spoil bank side)	4,024.4	0.073	293.78	108.52	31,881.01
Ramp road	19,871.5	0.043	854.47	53.50	45,714.15
Remaining spoil banks	9,075.0	0.043	390.23	830.10	323,929.92
Total overburden cost					\$444,507.87

Topsoil to be Redistributed				
Area	Acres	Conversion factor + 1	Flat acre	Total yardage
Initial spoil bank	143.87	1.000	672.22	96,712.29
Highwall (highwall side)	16.03	1.060	672.22	11,422.23
(spoil bank side)	99.38	1.000	672.22	66,805.22
Remaining spoil banks	830.10	1.000	672.22	558,009.82
Total acres topsoiled	1,089.38			732,949.56

672.81 yards of topsoil are salvaged per acre.

Topsoil Cost Summary					
Area	Acres	Average yardage/acre	Yardage	Cost yard	Cost
Stockpiling (area I')	44.29	672.81	29,798.75	\$0.225	\$6,704.72
(1,2,3, & ISB)	160.00	672.81	107,649.70	0.432	46,504.63
Direct distribution	885.09	672.81	595,497.40	0.693	412,679.69
Redistribution (area I')	44.29	672.81	29,798.75	0.225	6,704.72
(highwall proximity)	160.00	672.81	107,649.70	0.600	64,589.76
Total topsoiling cost					\$537,183.52

Revegetation Cost

1,089.38 acres times \$96.57 per acre = \$105,201.42.

Miscellaneous and Unallocated Costs

1,089.38 acres times \$100.00 per acre = \$108,938.00.

Total Cost Summary

Recontouring	\$444,507.87
Topsoiling	537,183.52
Revegetation	105,201.42
Miscellaneous and unallocated costs	108,938.00
Total cost	\$1,195,830.81

Cost per acre mined is \$1,195.83.

Table 6.10
Cost Summary

Reclamation goal: grazing; Topsoil depth: 4"; Highwall height: 22 yards;
Overburden depth: 16 yards; All reclaimed slopes: 5%.

Area	Recontouring Cost Summary			Acres	Cost
	Yardage/acre moved	Cost/yard moved	Cost/ acre		
Initial spoil bank	18,088.8	\$0.084	\$1,519.46	118.34	\$179,812.89
Highwall (highwall side)	3,065.5	0.155	475.15	213.77	101,572.81
(spoil bank side)	12,077.4	0.122	1,473.44	213.77	314,977.26
Ramp road	43,439.0	0.048	2,085.07	105.70	220,391.89
Remaining spoil banks	9,075.0	0.043	390.23	667.89	260,630.71
Total overburden cost					\$1,077,385.56

Area	Topsoil to be Redistributed			Total yardage
	Acres	Conversion factor + 1	Flat acre	
Initial spoil bank	259.98			
Highwall	319.77	1.000	672.22	838,688.56
Remaining spoil banks	667.89			
Total acres topsoiled	1,247.64			

672.22 yards of topsoil are salvaged per acre.

Area	Topsoil Cost Summary			Cost yard	Cost
	Acres	Average yardage/acre	Yardage		
Stockpiling (area I')	101.64	672.22	63,324.4	\$0.225	\$15,372.99
(1,2,3 & ISB)	160.00	672.22	107,555.2	0.432	46,463.85
Remaining area	986.00	672.22	662,808.9	0.693	459,326.56
Redistribution (area I')	101.64	672.22	68,324.4	0.225	15,372.99
(highwall proximity)	160.00	672.22	107,555.2	0.617	66,361.56
Total topsoiling cost					\$602,897.95

Revegetation Cost

1,177.29 acres times \$96.57 per acre = \$113,690.89.

Miscellaneous and Unallocated Costs

1,177.29 acres times \$100.00 per acre = \$117,729.00.

Total Cost Summary

Recontouring	\$1,077,385.56
Topsoiling	602,897.95
Revegetation	113,690.89
Miscellaneous and unallocated costs	117,729.00
Total cost	\$1,944,480.51

Cost per acre mined is \$1,944.48.

Table 6.11
Cost Summary

Reclamation goal: grazing; Topsoil depth: 4"; Highwall height: 22 yards;
Overburden depth: 16 yards; All reclaimed slopes: 10%.

Recontouring Cost Summary					
Area	Yardage/acre moved	Cost/yard moved	Cost/ acre	Acres	Cost
Initial spoil bank	25,745.3	\$0.065	\$1,673.44	70.82	\$118,513.02
Highwall (highwall side)	6,548.9	0.117	766.22	152.58	116,909.84
(spoil bank side)	11,627.6	0.094	1,092.99	152.58	166,768.41
Ramp road	40,414.0	0.048	1,939.87	105.70	205,044.25
Remaining spoil banks	8,470.0	0.043	364.21	776.60	282,845.48
Total overburden cost					\$890,081.00

Topsoil to be Redistributed				
Area	Acres	Conversion Factor + 1	Flat acre	Total yardage
Initial spoil bank	194.85			
Highwall	217.98	1.005	672.22	796,800.58
Remaining spoil banks	776.60			
Total acres topsoiled	1,179.43			

675.58 yards of topsoil are salvaged per acre.

Topsoil Cost Summary					
Area	Acres	Average yardage/acre	Yardage	Cost yard	Cost
Stockpiling (area I')	74.03	675.58	50,013.19	\$0.225	\$11,252.97
(1,2,3 & ISB)	160.00	675.58	108,092.80	0.432	46,696.09
Remaining area	945.40	675.58	638,693.33	0.693	442,614.47
Redistribution (area I')	74.03	675.58	50,013.19	0.225	11,252.97
(highwall proximity)	160.00	675.58	108,092.80	0.612	66,152.79
Total topsoiling cost					\$577,969.29

Revegetation Cost

1,179.43 acres times \$96.57 per acre = \$113,897.55.

Miscellaneous and Unallocated Costs

1,179.43 acres times \$100.00 per acre = \$117,943.00.

Total Cost Summary

Recontouring	\$890,081.00
Topsoiling	577,969.29
Revegetation	113,897.55
Miscellaneous and unallocated costs	117,943.00
Total cost	\$1,699,890.84

Cost per acre mined is \$1,699.89.

Table 6.12
Cost Summary

Reclamation goal: grazing; Topsoil depth: 4"; Highwall height: 22 yards;
Overburden depth: 16 yards; All reclaimed slopes: 20%.

Recontouring Cost Summary					
Area	Yardage/acre moved	Cost/yard moved	Cost/ acre	Acres	Cost
Initial spoil bank	33,023.7	\$0.051	\$1,684.21	38.93	\$65,566.30
Highwall (highwall side)	7,769.1	0.099	769.14	109.83	84,474.65
(spoil bank side)	8,262.5	0.074	611.43	109.83	67,153.36
Ramp road	34,364.0	0.048	1,649.47	105.70	174,348.97
Remaining spoil banks	7,260.0	0.043	312.18	851.24	265,740.10
Total overburden cost					\$657,283.38

Topsoil to be Redistributed				
Area	Acres	Conversion factor +1	Flat acre	Total yardage
Initial spoil bank	131.11			
Highwall	153.28	1.02	672.22	778,661.06
Remaining spoil banks	851.24			
Total acres topsoiled	1,135.63			

685.66 yards to topsoil must be salvaged per acre mined.

Topsoil Cost Summary					
Area	Acres	Average Yardage/acre	Yardage	Cost Yard	Cost
Stockpiling (area I')	52.18	685.66	35,777.7	\$0.225	\$8,049.98
(1,2,3 & ISB)	160.00	685.66	109,705.6	0.432	47,392.82
Remaining area	923.45	685.66	633,172.7	0.693	438,788.68
Redistribution (area I')	52.18	685.66	35,777.7	0.225	8,049.98
(highwall proximity)	160.00	685.66	109,705.6	0.608	66,701.00
Total topsoiling cost					\$568,982.46

Revegetation Cost

1,135.63 acres times \$96.57 per acre = \$109,667.78.

Miscellaneous and Unallocated Costs

1,135.63 acres times \$100.00 per acre = \$113,563.00.

Total Cost Summary

Recontouring	\$657,283.38
Topsoiling	568,982.46
Revegetation	109,667.78
Miscellaneous and unallocated costs	113,567.00
Total cost	\$1,449,500.62

Cost per acre mined is \$1,449.50.

Table 6.13
Cost Summary

Reclamation goal: grazing; Topsoil depth: 4"; Highwall height: 22 yards;
Overburden depth: 16 yards; Reclaimed highwall slope: 20%; All reclaimed
slopes: 5%.

Area	Recontouring Cost Summary				
	Yardage/acre moved	Cost/yard moved	Cost/ acres	Acres	Cost
Initial spoil bank	18,088.8	\$0.084	\$1,519.46	118.34	\$179,812.89
Highwall (highwall side)	1,640.4	0.072	118.11	213.77	25,248.37
(spoil bank side)	12,077.4	0.122	1,473.44	213.77	314,977.26
Ramp road	43,439.0	0.048	2,085.07	105.70	220,391.89
Remaining spoil banks	9,075.0	0.043	390.23	667.89	260,630.71
Total overburden cost					\$1,001,061.12

Area	Topsoil to be Redistributed			
	Acres	Conversion factor + 1	Flat acre	Total yardage
Initial spoil bank	259.98	1.000	672.22	174,763.75
Highwall (highwall side)	51.16	1.020	672.22	35,078.59
(spoil bank side)	184.66	1.000	672.22	124,132.14
Remaining spoil banks	667.89	1.000	672.22	448,969.01
Total acres topsoiled	1,163.69			

672.81 yards of topsoil are salvaged per acre.

Area	Topsoil Cost Summary			
	Acres	Average yardage/acre	Yardage	Cost
Stockpiling (area I')	101.64	672.81	68,384.41	\$0.225
(1,2,3 & ISB)	160.00	672.81	107,649.60	0.432
Direct distribution	902.05	672.81	606,908.26	0.693
Redistribution (area I')	101.64	672.81	68,384.41	0.225
(highwall proximity)	160.00	672.81	107,649.60	0.604
Total topsoiling cost				\$562,992.19

Revegetation Cost

1,163.69 acres time \$96.57 per acre = \$112,377.54.

Miscellaneous and Unallocated Costs

1,163.69 acres times \$100.00 per acre = \$116,369.00.

Total Cost Summary

Recontouring	\$1,001,061.12
Topsoiling	562,992.19
Revegetation	112,377.54
Miscellaneous and unallocated costs	116,369.00
Total cost	\$1,792,799.85

Cost per acre mined is \$1,792.80.

Table 6.14
Cost Summary

Reclamation goal: grazing; Topsoil depth: 4"; Highwall height: 22 yards;
Overburden depth: 16 yards; Reclaimed highwall slope: 35%; All reclaimed
slopes: 5%.

Area	Recontouring Cost Summary			Acres	Cost
	Yardage/acre moved	Cost/yard moved	Cost per acre		
Initial spoil bank	18,088.8	\$0.084	\$1,519.46	118.34	\$179,812.89
Highwall (highwall side)	931.80	0.072	67.09	213.77	14,341.83
(spoil bank side)	12,077.4	0.122	1,473.44	213.77	314,977.26
Ramp road	43,439.0	0.048	2,085.07	105.70	220,391.89
Remaining spoil banks	9,075.0	0.043	390.23	667.89	260,630.71
Total overburden cost					\$990,154.58

Area	Topsoil to be Redistributed			Total yardage
	Acres	Conversion factor + 1	Flat acre	
Initial spoil bank	259.98	1.000	672.22	174,763.75
Highwall (highwall side)	43.52	1.060	672.22	31,010.32
(spoil bank side)	184.66	1.000	672.22	124,132.14
Remaining spoil banks	667.89	1.000	672.22	448,969.01
Total acres topsoiled	1,156.05			778,875.22

673.74 yards of topsoil are salvaged per acre.

Area	Topsoil Cost Summary			Cost yard	Cost
	Acres	Average yardage/acre	Yardage		
Stockpiling (area I')	101.64	673.74	68,478.9	\$ 0.225	\$ 15,407.75
(1,2,3 & ISB)	160.00	673.74	107,789.4	0.432	46,568.91
Direct distribution	894.41	673.74	602,599.8	0.693	417,601.66
Redistribution (Area I')	101.64	673.74	68,478.9	0.225	15,407.75
(highwall proximity)	160.00	673.74	107,789.4	0.602	64,894.64
Total topsoiling cost					\$ 559,880.71

Revegetation Cost

1,156.05 acres times \$96.57 per acre = \$111,639.74.

Miscellaneous and Unallocated Costs

1,156.05 acres times \$100.00 per acre = \$115,605.00.

Total Cost Summary

Recontouring	\$990,154.58
Topsoiling	559,880.71
Revegetation	111,639.74
Miscellaneous and unallocated costs	115,605.00
Total cost	\$1,777,280.03

Cost per acre mined is \$1,777.28.

Table 6.15
Cost Summary

Reclamation goal: grazing; Topsoil depth: 4"; Highwall height: 44 yards;
Overburden depth: 32.00; All reclaimed slopes: 5%.

Recontouring Cost Summary					
Area	Yardage/acre moved	Cost/yard moved	Cost acre	Acres	Cost
Initial spoil bank	22,910.4	\$0.109	\$2,497.23	179.88	\$449,201.73
Highwall (highwall side)	9,101.2	0.184	1,674.62	342.77	574,009.49
(spoil bank side)	21,347.1	0.189	4,034.60	342.77	1,382,939.80
Ramp road	98,945.0	0.057	5,639.87	238.51	1,345,165.30
Remaining spoil banks	9,075.0	0.043	390.23	477.35	186,276.29
Total overburden cost					\$3,937,592.61

Topsoil to be Redistributed				
Area	Acres	Conversion factor + 1	Flat acre	Total Yardage
Initial spoil bank	369.20			
Highwall	504.77	1.000	672.22	908,384.33
Remaining spoil banks	477.35			
Total acres topsoiled	1,351.32			

672.22 yards of topsoil are salvaged per acre.

Topsoil Cost Summary					
Area	Acres	Average yardage/acre	Yardage	Cost yard	Cost
Stockpiling (area I')	149.32	672.22	100,375.9	\$0.225	\$22,584.58
(1,2,3 & ISB)	160.00	672.22	107,555.2	0.432	46,463.85
Remaining area	1,042.00	672.22	700,453.2	0.693	485,414.06
Redistribution (area I')	149.32	672.22	100,375.9	0.225	22,584.58
(highwall proximity)	160.00	672.22	107,555.2	0.630	67,759.78
Total topsoiling cost					\$644,806.85

Revegetation Cost

1,351.32 acres times \$96.57 per acre = \$130,496.97.

Miscellaneous and Unallocated Costs

1,351.32 acres times \$100 per acre = \$135,132.00.

Total Cost Summary

Recontouring	\$3,937,592.61
Topsoiling	644,806.85
Revegetation	130,496.97
Miscellaneous and unallocated costs	135,132.00
Total cost	\$4,848,028.43

Cost per acre mined is \$4,848.03

Table 6.16
Cost Summary

Reclamation goal: grazing; Topsoil depth: 4"; Highwall height: 44 yards;
Overburden depth: 32 yards; All reclaimed slopes: 10%.

Recontoured Cost Summary					
<u>Area</u>	<u>Yardage/acre moved</u>	<u>Cost/yard moved</u>	<u>Cost/ acre</u>	<u>Acres</u>	<u>Cost</u>
Initial spoil bank	31,143.0	\$0.084	\$2,616.01	107.34	\$280,802.51
Highwall (highwall side)	11,114.0	0.163	1,811.58	244.74	443,366.08
(spoil bank side)	22,171.3	0.138	3,059.64	244.74	748,816.29
Ramp road	92,290.0	0.057	5,260.53	238.51	1,254,689.00
Remaining spoil banks	7,865.0	0.043	338.20	647.92	219,126.54
Total overburden cost					\$2,946,801.42

Topsoil to be Redistributed				
<u>Area</u>	<u>Acres</u>	<u>Conversion Factor + 1</u>	<u>Flat Acre</u>	<u>Total yardage</u>
Initial spoil bank	264.16			
Highwall	352.54	1.005	672.22	854,353.37
Remaining spoil banks	647.92			
Total acres topsoiled	1,264.62			

675.58 yards of topsoil must be salvaged per acre disturbed.

Topsoil Cost Summary					
<u>Area</u>	<u>Acres</u>	<u>Average yardage/acre</u>	<u>Yardage</u>	<u>Cost yard</u>	<u>Cost</u>
Stockpiling (area I')	116.82	675.58	78,921.3	\$0.225	\$17,757.29
(1,2,3 & ISB)	160.00	675.58	108,092.8	0.432	46,696.09
Remaining Area	987.80	675.58	667,337.9	0.693	462,465.16
Redistribution (area I')	116.82	675.58	78,921.3	0.225	17,757.29
(highwall proximity)	160.00	675.58	108,092.8	0.620	67,017.54
Total topsoiling cost					\$611,693.37

Revegetation Cost

1,264.62 acres times \$96.57 per acre = \$122,124.35.

Miscellaneous and Unallocated Costs

1,264.62 acres times \$100 per acre = \$126,462.00.

Total Cost Summary

Recontouring	\$2,946,801.42
Topsoiling	611,693.37
Revegetation	122,124.35
Miscellaneous and unallocated costs	126,462.00
Total cost	\$3,807,081.14

Cost per acre mined is \$3,807.08.

Table 6.17
Cost Summary

Reclamation goal: grazing; Topsoil depth: 4"; Highwall height: 44 yards;
Overburden depth: 32 yards; All reclaimed slopes: 20%.

Area	Recontouring Cost Summary				Acres	Cost
	Yardage/acre moved	Cost/yard moved	Cost/ acre			
Initial spoil bank	38,778.1	\$0.065	\$2,520.58	59.19	\$149,193.13	
Highwall (highwall side)	13,541.1	0.124	1,679.10	176.10	295,857.42	
(spoil bank side)	18,740.4	0.106	1,986.48	176.20	350,017.77	
Ramp road	78,980.0	0.057	4,501.86	238.51	1,073,738.61	
Remaining spoil banks	7,260.0	0.043	312.18	764.61	238,695.94	
Total overburden cost					\$2,107,502.87	

Area	Topsoil to be Redistributed			Total yardage
	Acres	Conversion factor + 1	Flat acre	
Initial spoil bank	187.81			
Highwall	248.0	1.02	672.2	823,085.25
Remaining spoil banks	764.61			
Total acres topsoiled	1,200.42			

685.66 yards of topsoil are salvaged per acre.

Area	Topsoil Cost Summary			Cost yard	Cost
	Acres	Average yardage/acre	Yardage		
Stockpiling (area I')	88.62	685.66	60,763.2	\$0.225	\$13,671.72
(1,2,3 & ISB)	160.00	685.66	109,705.6	0.432	47,392.82
Remaining area	951.80	685.66	652,611.2	0.693	452,259.56
Redistribution (area I')	88.62	685.66	60,763.2	0.225	13,671.72
(highwall proximity)	160.00	685.66	109,705.6	0.613	67,249.53
Total topsoiling cost					\$594,245.35

Revegetation Cost

1,200.42 acres times \$96.57 per acre = \$115,924.55.

Miscellaneous and Unallocated Costs

1,200.42 acres times \$100.00 per acre = \$120,042.00.

Total Cost Summary

Recontouring	\$2,107,502.87
Topsoiling	594,245.35
Revegetation	115,924.55
Miscellaneous and unallocated costs	120,042.00
Total cost	\$2,937,714.77

Cost per acre mined is \$2,937.71.

Table 6.18

Cost Summary

Reclamation goal: grazing: Topsoil depth: 4"; Highwall height: 44 yards;
Overburden depth: 32 yards; Reclaimed highwall slope: 20%; All reclaimed
slopes: 5%.

Area	Recontouring Cost Summary				
	Yardage/acre moved	Cost/yard moved	Cost per acre	Acres	Cost
Initial Spoil bank	22,910.4	\$ 0.109	\$2,497.23	179.88	\$449,201.73
Highwall (highwall side)	2,839.4	0.110	312.33	342.77	107,057.35
(spoil bank side)	21,347.1	0.189	4,034.60	342.77	1,382,939.80
Ramp road	98,945.0	0.507	5,639.87	238.51	1,345,165.30
Remaining spoil banks	9,075.0	0.043	390.23	477.35	186,276.29
Total overburden cost					\$3,470,640.47

Area	Topsoil to be Redistributed			
	Acres	Conversion Factor + 1	Flat Acre	Total yardage
Initial spoil bank	369.20	1.000	672.22	248,183.62
Highwall (highwall side)	125.23	1.020	672.22	85,865.75
(spoil bank side)	260.94	1.000	672.22	175,409.08
Remaining spoil banks	477.35	1.000	672.22	320,884.21
Total acres topsoiled	1,232.72			830,342.66

673.59 yards of topsoil are salvaged per acre.

Area	Topsoil Cost Summary			
	Acres	Average yardage/acre	Yardage	Cost
Stockpiling (area I')	149.32	673.59	100,580.45	\$ 0.225 \$ 22,630.60
(1,2,3 & ISB)	160.00	673.59	107,774.40	0.432 46,558.54
Direct distribution	880.00	673.59	592,759.20	0.693 410,782.12
Redistribution (area I')	149.32	673.59	100,580.45	0.225 22,630.60
(highwall proximity)	160.00	673.59	107,774.40	0.608 65,526.84
Total topsoiling cost				\$568,128.70

Revegetation Cost

1,232.72 acres time \$96.57 per acre = \$119,043.77.

Miscellaneous and Unallocated Costs

1,232.72 acres times \$100.00 per acre = \$123,272.00.

Total Cost Summary

Recontouring	\$3,470,640.47
Topsoiling	568,128.70
Revegetation	119,043.77
Miscellaneous and unallocated costs	123,272.00
Total cost	\$4,281,084.98

Cost per acre mined is \$4,281.08

Table 6.19

Cost Summary

Reclamation goal: grazing; Topsoil depth: 4"; Highwall height: 44 yards;
Overburden depth: 32 yards; Reclaimed highwall slope: 35%; All reclaimed
slopes: 5%.

Recontouring Cost Summary					
Area	Yardage/ acre moved	Cost/yard moved	Cost per acre	Acres	Cost
Initial spoil bank	22,910.4	\$ 0.109	\$ 2,497.23	179.88	\$ 449,201.73
Highwall (highwall side)	1,612.9	0.085	137.10	342.77	46,993.77
(spoil bank side)	21,347.1	0.189	4,034.60	342.77	1,382,939.80
Ramp road	98,945.0	0.057	5,639.87	238.51	1,345,165.30
Remaining spoil banks	9,075.0	0.043	390.23	477.35	186,276.29
Total overburden cost					\$ 3,410,576.89

Topsoil to be Redistributed				
Area	Acres	Conversion Factor + 1	Flat Acre	Total Yardage
Initial spoil bank	369.20	1.000	672.22	248,183.62
Highwall (highwall side)	75.85	1.060	672.22	54,047.16
(spoil bank side)	290.92	1.000	672.22	195,562.24
Remaining spoil banks	477.35	1.000	672.22	320,884.21
Total acres topsoils	1,213.32			818,677.23

674.74 yards of topsoil are salvaged per acre.

Topsoil Cost Summary					
Area	Acres	Average yardage/acre	Yardage	Cost yard	Cost
Stockpiling (area I')	149.32	674.74	100,752.17	\$ 0.025	\$ 22,669.24
(1,2,3 & ISB)	160.00	674.74	107,958.40	0.432	46,638.03
Direct distribution	904.00	674.74	609,964.96	0.693	422,705.71
Redistribution (Area I')	149.32	674.74	100,752.17	0.225	22,669.24
(highwall proximity)	160.00	674.74	107,958.40	0.604	65,206.87
Total topsoiling cost					\$ 579,889.09

Revegetation Cost

1,213.32 acres times \$96.57 per acre = \$117,170.31.

Miscellaneous and Unallocated Costs

1,213.32 acres times \$100.00 per acre = \$121,332.00.

Total Cost Summary

Recontouring	\$ 3,410,576.89
Topsoiling	579,889.09
Revegetation	117,170.31
Miscellaneous and unallocated costs	121,332.00
Total cost	\$ 4,228,968.29

Cost per acre mined is \$4,284.45,

Table 6.20

Topsoil Analysis

Changing the depth of topsoil has an effect on cost. If the topsoil depth is increased by 50% (from 4" to 6"), the cost of topsoiling increases by 50%.

Cost Summary

Reclamation goal: grazing; Topsoil depth: 6"; Highwall height: 7.04 yards; Overburden depth: 5.12 yards; Highwall slope: 20%; Slope opposite highwall: 5%; Initial spoil bank: 5%; Remaining slope: 0%; Original slope: 0%.

Total Cost Summary

Overburden manipulation	\$ 472,974.90
Topsoiling	810,293.19
Revegetation	105,852.30
Miscellaneous and unallocated costs	<u>109,612.00</u>
Total cost	\$ 1,498,732.39

Cost per acre mined is \$1,498.73.

Cost Summary

Reclamation goal: grazing; Topsoil depth: 2"; Highwall height: 7.04 yards; Overburden depth: 5.12 yards; Highwall slope 20%; Slope opposite highwall: 5%; Initial spoil bank: 5%; Remaining slope: 0%; Original slope: 0%.

Total Cost Summary

Overburden manipulation	\$ 472,974.90
Topsoiling	270,097.73
Revegetation	105,852.30
Miscellaneous and unallocated costs	<u>109,612.00</u>
Total cost	\$ 958,536.93

Cost per acre mined is \$958.54.

Chapter 7

Summary, Conclusions, and Comments ✓

Summary

This study has estimated the influence of overburden depth, reclaimed slope, topsoil depth desired, and reclamation goal on reclamation cost. This study does not provide a reclamation cost estimate for every situation but provides a method of estimating reclamation cost under certain conditions.

Overburden depth influences reclamation cost. For instance, with a 5% reclaimed slope, the reclamation cost per acre increases from \$1,239.90 at 7.04 yards of overburden (Table 7.01) depth to \$4,848.03 at 44 yards or an increase in cost of 291%.

Table 7.01. Reclamation Cost per Acre of Various Overburden Depths and Reclaimed Slopes.³²

Overburden depth (Yds.)	5.12	16	32
Reclaimed Slope (%)			
5	\$1,239.90	\$1,944.48	\$4,848.03
10	1,170.26	1,699.89	3,807.08
20	1,075.39	1,499.50	2,937.71

Changing the reclaimed slope has a larger effect on overburden

³² Assumptions on page 56.

manipulation cost as the depth of the overburden increases. Reclamation cost per acre with an overburden depth of 7.04 yards increased from \$1,075.39 (Table 7.01) with a reclaimed slope of 20% to \$1,239.90 with a reclaimed slope of 5%, which is a 15% increase in cost to reduce the slope an additional 15%. Reclamation cost per acre with an overburden depth of 44 yards increases from \$2,937.71 with a reclaimed slope of 20% to \$4,848.03 with a reclaimed slope of 5% for an increase of 65% in cost for an additional 15% slope reduction. Closer examination shows that these costs increase at a greater rate in the highwall area, ramp road area, and in the initial spoil bank area than in the remaining spoil banks. (The cost per acre in the remaining spoil bank area remains constant as the overburden depth increases and the slope remains the same. Per acre costs are misleading in other areas but total cost for other areas indicate that the large cost increase is due to changes in cost in the ramp road, highwall, and initial spoil bank areas. Refer to Tables 6.06 and 6.15.)

The slope of the reclaimed highwall affects the cost of reclamation. Referring to Table 7.02, several conclusions can be reached. As the reclaimed highwall slope decreases, the reclamation cost increases more than proportionately. For instance, if the highwall height is 7.04 yards, and the reclaimed highwall slope decreases from 35% to 20%, recontouring costs increase from \$3,277.30 to \$5,770.01 for an increase in recontouring costs of 76%. However, if the reclaimed slope decreases from

20% to 5%, the recontouring cost increases from \$5,770.01 to \$15,410.26 for an increase in cost of 167%. As the highwall height increases, the more than proportionate increase in recontouring cost becomes more pronounced. As illustrated in Table 7.02, the highwall height influenced recontouring, and therefore the reclamation cost. As the highwall height increases, the cost of recontouring the highwall increases.

Table 7.02. Recontouring Cost per Acre of the Highwall in Regard to³³ Various Highwall Heights and Reclaimed Highwall Slopes.

Highwall Heights (Yds.)	7.04	22	44
Reclaimed Highwall Slope (%)			
5	\$15,410.26	\$101,572.81	\$574,009.49
20	5,770.01	25,248.37	107,057.35
35	3,277.30	14,341.83	46,993.77

As the highwall slope decreases, the area to be topsoiled and revegetated also increases. The influence of recontouring to differing highwall slopes on average reclamation cost per acre over the entire area to be reclaimed may be large or small, depending not only on the slope of the reclaimed contour and highwall height but also upon the design of the area to be reclaimed. If the highwall area is relatively small in comparison to the rest of the area to be reclaimed, then the

³³ Assumption on page 56.

influence on per acre reclamation cost by the highwall area will be relatively small. As the highwall area becomes larger in relation to the rest of the area to be reclaimed, the influence of various highwall heights and reclaimed highwall slopes on reclamation cost becomes larger.

Topsoiling costs increase almost proportionally to topsoil depth desired (Table 7.03). Therefore, reclamation cost per acre increases consistently as desired topsoil depth increases. Overburden depth has a small effect on the change in topsoiling costs due to changes in depth of topsoil desired.

Table 7.03. Reclamation Cost per Acre of Various Overburden Depths and Topsoil Depths.³⁴

Overburden depths (Yds.)	5.12	16	32
Topsoil depths (in.)			
2	\$961.61	\$1,643.03	\$4,525.63
4	1,239.90	1,944.49	4,848.03
6	1,518.28	2,245.93	5,178.43

Reclaimed slope has a small effect on topsoiling cost. (Topsoiling costs increase by 2% from a 0% to a 20% reclaimed slope, and have a smaller effect on total reclamation cost.)

The reclamation goal may or may not have a large effect on

³⁴ Assumption on page 56.

reclamation cost. Changing the reclamation goal from grazing (reclamation cost \$1,239.90 per acre, Table 7.04) to cropland (reclamation cost \$1,197.58 per acre) decreases reclamation cost per acre by 3%. However, changing the reclamation goal from grazing (reclamation cost \$1,239.90 per acre) to grazing and trees - 1000 per acre (reclamation cost \$2,370.27 per acre) increases reclamation cost by 91%.

Table 7.04. Reclamation Cost per acre of Various Reclamation Goals.³⁵

Goal	Total Reclamation Cost Per Acre
Grazing	\$1,239.90
Cropland	1,197.58
Grassland and Trees (1000 trees per acre planted as seedlings)	2,370.27

The reclamation cost estimates as generated in this study may be inaccurate in certain situations. For instance, other equipment may be used for reclamation, rather than the equipment assumed, due to availability. Mining area characteristics such as problems with water or overburden toxicity may have a large influence on reclamation cost and are not accounted for in this study. Even though allowances have been made for seasonality of certain activities, weather may cause reclamation cost to differ from estimates. In certain cases, the methods of revegetation may not provide an acceptable revegetation

³⁵ All assumptions are the same as for Table 6.06 except for the reclamation goal.

environment and other additions or amendments may become necessary.

Conclusions and Comments

Some variables have a larger influence on reclamation cost than other variables. Overburden depth has a large influence on reclamation cost. The reclaimed slope has a small influence on reclamation cost if the overburden depth is small (7.04 yards); however, as the overburden depth increases, so does the influence of the reclaimed slope on reclamation cost. (The range of reclaimed slopes considered are from 0% - 20%.) As the highwall height increases or the reclaimed highwall slope decreases, the cost of recontouring the highwall increases. The influence of highwall recontouring costs on the reclamation cost per acre varies widely due to mine design along with the highwall height and reclaimed highwall slope. The cost of topsoiling varies directly with the depth of topsoil desired. Topsoiling costs are a significant portion of reclamation cost if only 2 inches of topsoil are desired on the reclaimed surface. (As topsoil depth increases on the reclaimed surface, topsoiling cost assumes a larger portion of reclamation cost.) Reclamation goal may or may not have a large influence on reclamation cost. Changing the reclamation goal from grazing to cropland has a minor influence on reclamation costs while including trees (in great numbers) in the reclamation goal will significantly increase reclamation cost.

Surface reclamation cost may be only a part of reclamation costs. Sub-surface reclamation may also be required and incur a cost. Extensive sub-surface reclamation could be expensive (relative to surface reclamation) especially where overburden depth is great and many layers of overburden must be segregated and/or replaced in a specified order. Sub-surface aquifers may be disturbed during mining and reclamation of these aquifers may be necessary. Replacement of aquifers would also increase reclamation costs, especially if it becomes necessary to replace the aquifer with material not readily available in the area to be reclaimed. It appears that the cost of sub-surface reclamation cost requiring any segregation of overburden or replacement of an aquifer would, at a minimum, equal the cost of surface reclamation.

The cost estimates provide information to help reclamation decision-makers. Hopefully a study will be done in which benefits of reclamation will be determined and the optimum reclamation level estimated.

Certain external benefits or benefits not valued in the market place along with market value should be considered in a benefit study. If the market value of the reclaimed land is less than the reclamation cost, certain externalities must be assumed if reclamation is justified. Externalities which have been suggested include aesthetic beauty, hunting, fishing, and simply the knowledge that the land is reclaimed and productive.

APPENDIX A

Appendix A

Method of Estimating the Volume of Spoils Moved to Recontour the Initial Spoil Bank Area.

Figure A.01. Cross-section of Initial Spoil Bank Area - Actual Post-Mining Contour

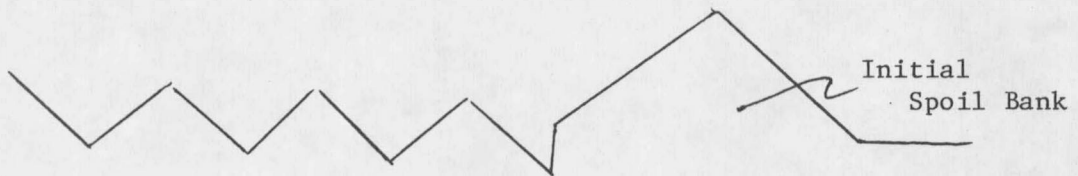
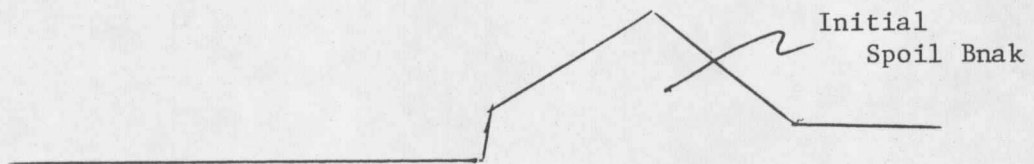


Figure A.02. Cross-section of Initial Spoil Bank Area - Assumed Post-Mining Contour



The same argument for use of the assumed contour to determine volume of overburden moved; rather than the actual contour used in the high-wall area, is again applicable here. (Refer to Figures A.01 and A.02.) Let AR_1 equal the area of the initial spoil bank (Figure A.02).

The area of AR1 can be estimated because:

$$AR1 = (D)(W)(SW + 1) \quad \text{Equation A.01}$$

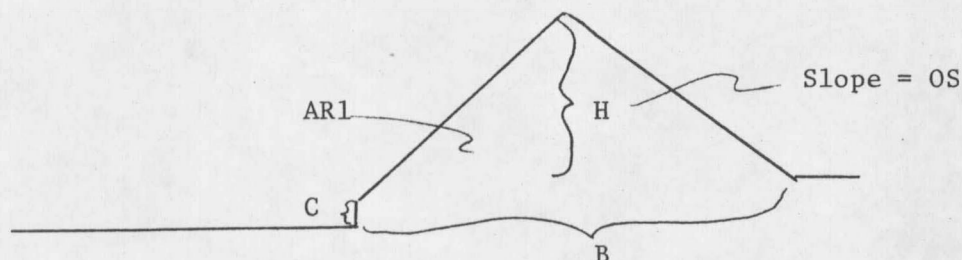
where: D = overburden depth

W = pit width

SW - swell factor from undisturbed overburden to disturbed spoil bank.

For later calculation distance C, H, and B must be found (Figure A.03).

Figure A.03. Cross-section of the Initial Spoil Bank



$$AR1 = \frac{(H)(B)}{2}$$

where: H = spoil bank height
B = spoil bank base

$$OS = \frac{H}{\frac{B}{2}}$$

where: OS - spoil bank slope

Therefore, since AR1 is known (from Equation A.01)

$$B = \frac{4AR1}{OS}$$

$$H = \frac{(OS)(B)}{2}$$

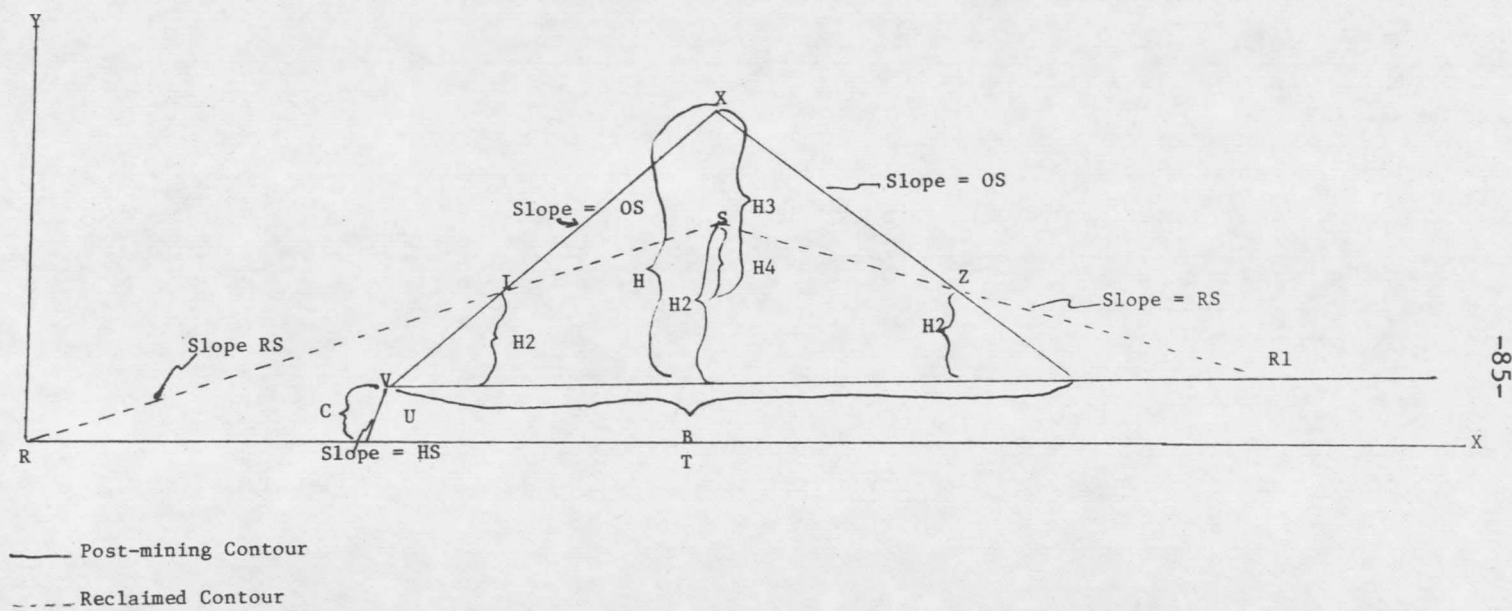
Also distance C can be found.

$$C = S - (SW)(D)$$

where: S = coal seam thickness
D = overburden depth
SW = swell factor

The area under the reclaimed slope (area RSRLVU in Figure A.04) must

Figure A.04. Labeled Cross-section of Initial Spoil Bank Area



equal the area of the initial spoil bank in its assumed post-mining contour (area VXY). Deriving equations for determining the area under the reclaimed contour and the assumed post-mining contour and setting these equations equal to each other will help find certain values, which facilitate the estimation of volume of spoils to be moved. In particular, if H1 (Figure A.04) is found, the volume moved to recontour the initial spoil bank area can be found. Setting up a coordinate axis on Figure A.04 such that the point where the reclaimed slope meets the assumed original contour of the spoil banks is the origin, and the X axis coincides with the assumed contour of the spoil banks, will be helpful.

Let:

$$\text{area AR1} = \text{VXY}$$

$$\text{area AR2} = \text{RST}$$

$$\text{area AR3} = \text{VUTW}$$

$$\text{area AR4} = \text{SWR1}$$

$$\text{area AR5} = \text{XIZ}$$

$$\text{area AR6} = \text{ISZ}$$

$$\text{area AR7} = \text{IXZS}$$

The area under the reclaimed slope (RSR1VU) is

$$\text{area RSR1VU} = \text{AR2} - \text{AR3} + \text{AR4}.$$

If expressions are found for AR2, AR3, and AR4, an expression for the area of RSR1VU can be found.

$$\text{AR2} = \frac{(\text{RT})(\text{ST})}{2}$$

$\overline{RT}$ = x coordinate of Point S

$\overline{ST}$ = y coordinate of Point S.

If the coordinates of Point S are known, then AR2 can be found. The equation for the line representing the reclaimed slope on the left side (RS) is

$$y = (RS)(x) \quad \text{Equation A.02.}$$

If H1 is some value equal to the height of the recontoured initial spoils bank from the peak to the undisturbed surface, then at Point S

$$y = H1 + C.$$

Substituting into Equation A.02 x equals $\frac{H1 + C}{RS}$

$$S \text{ coordinates } \left(\frac{H1}{RS} + \frac{C}{RS}, H1 + C \right)$$

$$AR2 = (H1^2)(E) + (H1)(F) + G$$

$$\text{where: } E = 1/(2RS)$$

$$F = C/RS$$

$$G = C^2/2RS$$

$$AR3 = \frac{(VW + UT)(C)}{2}$$

$$\overline{VW} = B/2$$

$$\overline{UT} = B/2 + C/HS$$

$$AR3 = \frac{(B)(C)}{2} + \frac{C^2}{HS}$$

$$\text{Let: } J = \frac{(B)(C)}{2} + \frac{C^2}{HS}$$

Then:

$$AR3 = J.$$

$$AR4 = \frac{(\overline{WR1})(H1)}{2}$$

$$\overline{WR1} = \frac{H1}{RS}$$

$$AR4 = \frac{H1^2}{2RS}$$

$$\text{because } RS = \frac{H1}{\overline{WR1}}$$

To find an expression for AR7, an expression for AR5 and AR6 must be found.

$$AR5 = \frac{H3^2}{OS}$$

$$AR6 = \frac{(\overline{IZ})(H4)}{2}$$

$$IZ = \frac{2H3}{OS}$$

$$H4 = \frac{(\overline{IZ})(RS)}{2}$$

$$AR6 = \frac{(H3^2)(RS)}{OS}$$

$$\text{because } OS = \frac{\overline{H3}}{\overline{IZ}}$$

$$\text{because } RS = \frac{H4}{\overline{IZ}}$$

Since

$$AR7 = AR5 - AR6,$$

$$AR7 = \frac{H3^2}{OS} - \frac{(H3^2)(RS)}{OS}$$

Assuming that the horizontal distance from Points R to V (hereafter referred to as L) is the portion considered to be reclaimed

$$L = \frac{H1}{RS} + \frac{C}{RS} - \frac{B}{2}$$

Dividing L into the area of an acre renders the distance or length of the cross-section needed to make an acre.

$$ACRE = \frac{\text{area of an acre}}{L}$$

where: ACRE = the distance or length of the cross-section needed to make an acre. Multiplying ACRE by AR7 produced a volume per acre basis.

$$AR4 = (H1^2)(E)$$

To find H1 set

$$AR1 = AR2 - AR3 + AR4$$

and solve for H1.

Proceeding to find AR7 which is the area to be moved.

$$AR7 = AR5 - AR6$$

$$AR5 = \frac{(H3)(IZ)}{2}$$

$$IZ = \frac{2H3}{OS}$$

$$\text{because } OS = \frac{H3}{\frac{IZ}{2}}$$

$$H3 = H - H2.$$

H2 can be found if the y coordinate of Point I are known (y coordinate of Point I minus C). The y coordinate can be found since the equation of the line representing slope of the recontoured spoil bank ($\overline{RS}$) is known and the line representing the left original spoil bank ($\overline{VX}$) can be found. The equation representing $\overline{VX}$ can be found by the point-slope method. The slope is OS and the coordinates of Point X are $\left(\frac{H1 + C}{RS}, H + C\right)$. Therefore the equation representing $\overline{VX}$ is

$$y = (OS)(x) + K$$

$$\text{where: } K = H + C - \frac{(H1)(OS)}{RS} - \frac{(OS)(C)}{RS}$$

Solving simultaneously, the equations representing the lines VX and RS for y and subtracting C, H2 is produced.

$$H2 = K / (1 - OS/RS)$$

Set: $M = K / (1 - OS/RS)$

Therefore: $H2 = M$

$$H3 = H - M$$

Method of Estimating the Volume of Spoils Moved to Recontour the High-wall Area

There are two variations of the reclaimed contour on the overburden side of the highwall area.

Figure A.05. Cross-section of Highwall Area Variation 1.

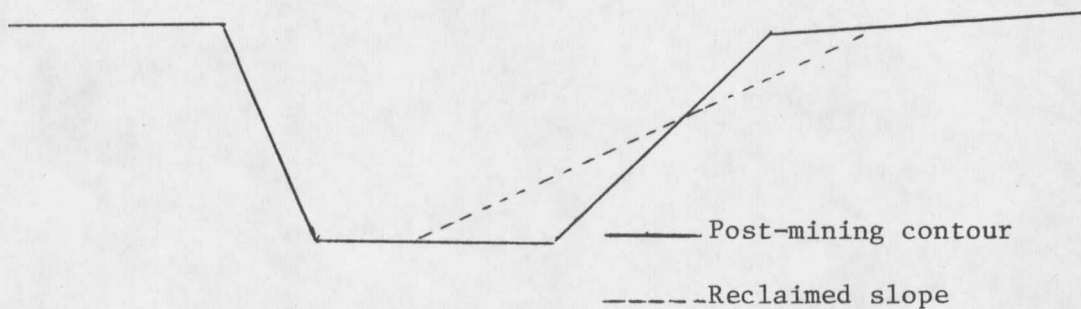
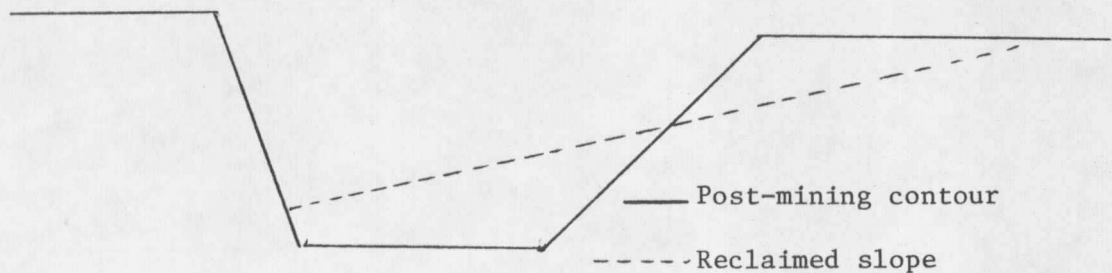


Figure A.06. Cross-section of Highwall Area Variation 2.



Whether Variation 1 (Figure A.05) or Variation 2 (Figure A.06) is incurred depends upon the depth of the overburden and the recontoured slope. First the derivation for Variation 2. See Figure A.07.

Knowns:

the pit width = W

the depth of spoils = H

the spoil bank slope = OS

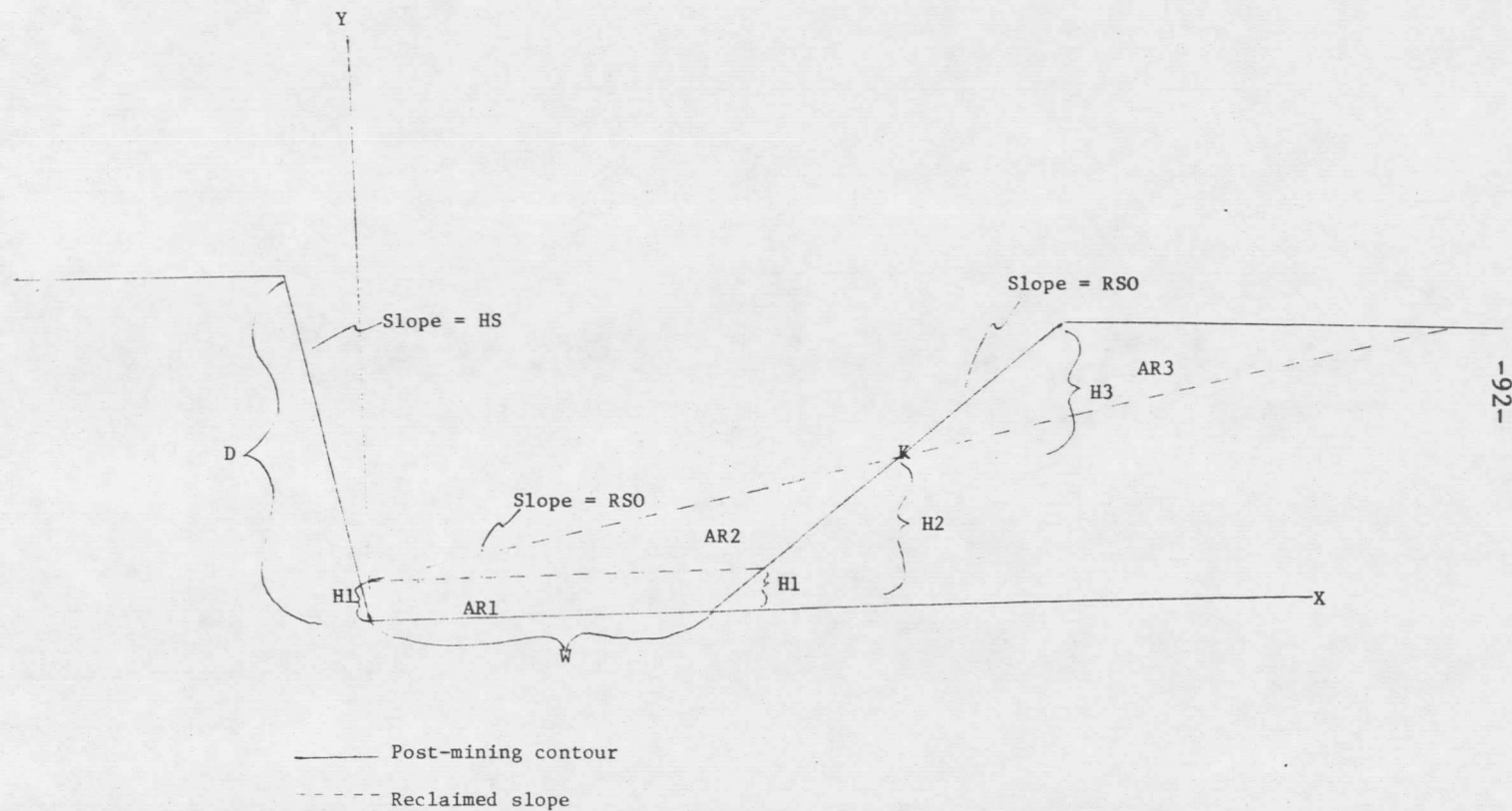
the reclaimed slope = RSO

the highwall slope = HS

the highwall depth = D

By equating the area of overburden to be moved ($AR3$, Figure A.07) with the area to be filled ($AR1$ plus $AR2$) the area moved can be found. Finding an expression for $AR1$, $AR2$, and $AR3$ in terms of $H1$, setting $AR1 + AR2 = AR3$, and solving for $H1$, the area moved can be estimated. (For convenience I have also used a coordinate system as shown in Figure A.07.) In the coordinate system all slopes are positive except the highwall slope. $H2$ must be found in terms of $H1$. Two equations can be found for the Y value of point K . The Y value for point K can be generated from the equation representing the highwall slope (HS), the spoil bank slope (OS), and the reclaimed slope (RS). Setting the latter two equations equal to each other, an expression for $H2$ can be found in terms of $H1$, since $H1$ and $H2$ also equal the Y value of point K . The formula representing the highwall slope is $Y1 = -(HS)(X1) = H1$ and the

Figure A.07. Labeled Cross-section of Highwall Area Variation 2.



formula representing the reclaimed slope is $Y_2 = (RSO)(X_2) + H_1$. The formula for line representing the spoil bank slope can be found through the use of a point and a slope. The slope equals OS. The point is found when the Y axis equals 0. The point where the highwall meets the bottom of the pit can be labeled $-H_1/HS, 0$. (Since $-H_1 = H_1/J$, then $J = -H_1/HS$.) Therefore, the point where the spoil bank meets the pit bottom is $W - H_1/HS, 0$. The equation of the line representing spoil bank slope is $Y_3 = (OS)(X_3) + (OS)(H_1)/HS - (OS)(W)$. If the line representing the spoil bank slope are solved simultaneously, the expression resulting is $W - \frac{H_1}{HS} - \frac{H_1}{RSO}$.

$$\frac{1}{RSO} - \frac{1}{OS}$$

Let:

$$C = \frac{1}{RSO} - \frac{1}{OS}$$

Solving for H_2 in terms of H_1 :

$$H_2 = \frac{W}{C} - \frac{H_1}{(C)(HS)} + \frac{H_1}{(C)(RSO)} - H_1.$$

$$\text{Let: } P = \frac{1}{(C)(HS)} - \frac{1}{(C)(RSO)} + 1$$

$$H_2 = \frac{W}{C} - (H_1)(P).$$

Finding an expression for the area of AR_2 in terms of H_1 :

$$AR_2 = \frac{H_2}{2} (W - \frac{H_1}{HS} + \frac{H_1}{OS})$$

Substituting for H_2 :

$$AR_2 = \frac{W^2}{2C} - \frac{(H_1)(W)}{2(C)(HS)} + \frac{(H_1)(W)}{2(OS)(C)} + \frac{(P)(H_1)(W)}{2} - \frac{(P)(H_1^2)}{2HS} + \frac{(P)(H_1^2)}{2OS}$$

AR1 is a parallelogram. The area of this parallelogram can be found in terms of H1.

$$AR1 = \frac{H1}{2} (W + W - \frac{H1}{HS} + \frac{H1}{OS})$$

$$AR1 = (W)(H1) - \frac{H1^2}{2HS} + \frac{H1^2}{2OS}$$

Finding an expression for the area of AR3 in terms of H1:

$$AR3 = \frac{(H3}{RSO} - \frac{H3}{OS}) \frac{(H3)}{2}$$

$$\text{Let: } Q = \frac{1}{2RSO} - \frac{1}{2OS}$$

$$AR3 = (H3^2)(Q)$$

$$H3 = H - H1 - H2$$

$$H3 = H - H1 - \frac{W}{C} - (P)(H1).$$

$$\text{Let: } R = H - \frac{W}{C}$$

$$S = 1 + P$$

$$H3 = R - (S)(H1)$$

$$AR3 = (R^2)(Q) - 2(RS)(H1)(Q) + (S^2)(H1^2)(Q).$$

Setting AR3 equal to AR2 + AR1 and solving for H1:

$$AR3 = AR2 + AR1$$

$$0 = AR3 - AR2 - AR1$$

$$0 = (R^2)(Q) - 2(RS)(H1)(Q) + (S^2)(H1^2)(Q) - (Q)(H1) + \frac{(H1^2)}{2HS} - \frac{(H1^2)}{2OS} - \frac{(W^2)}{2C} + \frac{(H1)(W)}{2(C)(HS)} - \frac{(H1)(W)}{2(C)(OS)} - \frac{(P)(H1)(W)}{2} + \frac{(P)(H1^2)}{2HS} - \frac{(P)(H1^2)}{2OS}.$$

Solve for H1 by the quadratic formula.

H1, H2, H3, AR1, AR2, and AR3 are known or can be found by

previously utilized formulas.

If Variation 1 (Figure A.08) is the appropriate cross section, then $H1$ can be set at 0 and $H2 = H3 = H/2$ and:

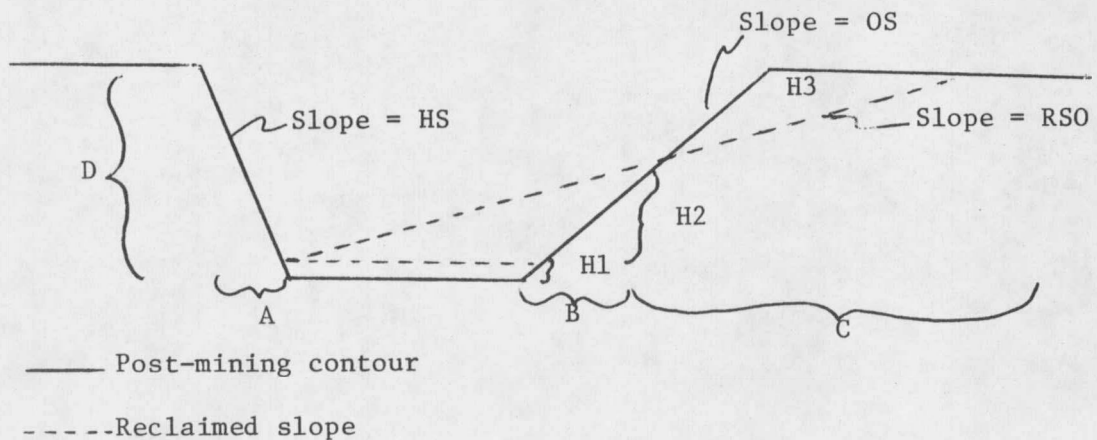
$$AR1 = 0$$

$$AR2 = (H1)(Q)$$

$$AR3 = (H3)(Q).$$

The width of the area reclaimed must be known if the volume to be moved is to be put on a per acre basis.

Figure A.08. Cross-section of the Highwall area to Determine Highwall Width.



$A + W + B + C$ = the length of the reclaimed cross section referred to as LE. (Refer to Figure A.08.)

Where:

$$A = \frac{-D}{HS} \quad (\text{Remember } HS \text{ is negative.})$$

$$B = \frac{H1 + H2}{OS}$$

$$C = \frac{H3}{RS0}$$

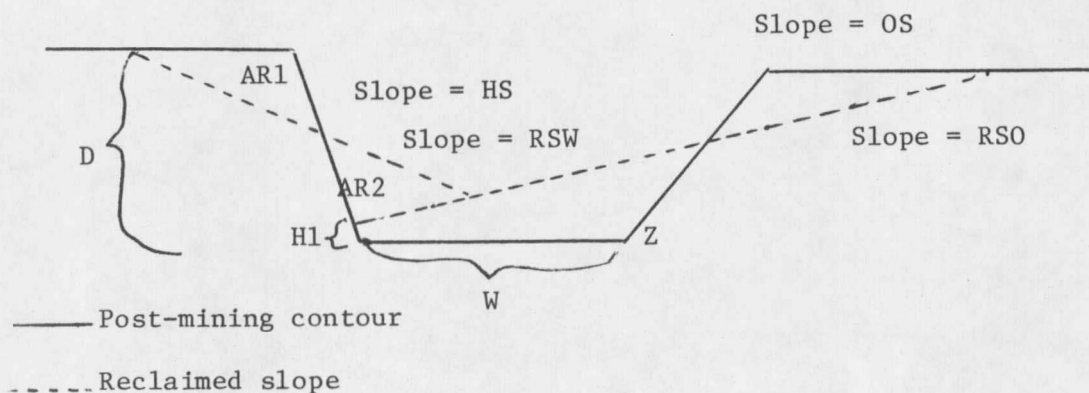
The area may be transferred to a volume per acre basis. Consider LE to be one side of a rectangle with an area equal to an acre. The other side must be equal to the area of an acre divided by LE.

Let: $ACRE = \text{area of an acre} / LE$

The volume per acre of yardage moved equals ACRE multiplied by AR3.

The volume of material which must be moved from the highwall side to produce the desired reclaimed slope depends on the height of the highwall, the desired slope on the highwall side, and the recontoured slope on the spoil bank side (Figure A.09).

Figure A.09. Cross-section of the Highwall Area.



We know:

- Overburden depth plus coal seam = D
- Reclaimed slope highwall side = RSW
- Reclaimed slope spoil bank side = RSO
- Spoil bank slope = OS
- Highwall slope = HS
- $H1$ and W_1 = from the Model on determining the yardage moved from the spoil bank. (If the reclaimed slope from the spoil bank side intersects the pit bottom, then W becomes the distance

between the intersection of the recontoured slope (spoil bank side) and the pit bottom and where the spoil bank intersects the pit bottom. Therefore, if H_1 is greater than 0, then $W=W^*$ (original) or pit width but if $H_1 = 0$, then $W=W^*$ (some new value).)

AR_1 may be found if D' is known. D' is defined as the vertical distance from the pit bottom to the point where the highwall intersects the reclaimed slope on the highwall side. Refer to Figure A.10. A solution may be found for D' by finding an expression for AR_1 and AR_2 in terms of D' , setting AR_1 equal to AR_2 , and solving for D' . A coordinate system such that the y axis passes point W in Figure A.10 and the X axis coincides with the pit bottom will facilitate the finding of an expression for AR_2 in terms of knowns and D' .

In order to find the area of AR_2 through the coordinate method points A, B, C, W, X, Y, and Z must be found.

Z coordinates (0,0)
W coordinates (0, D')
A coordinates $(-D', D)$
HS

$$\left(\text{Since } HS = \frac{D'}{ZA}, \text{ then } \overline{ZA} = \frac{HS}{D'}\right)$$

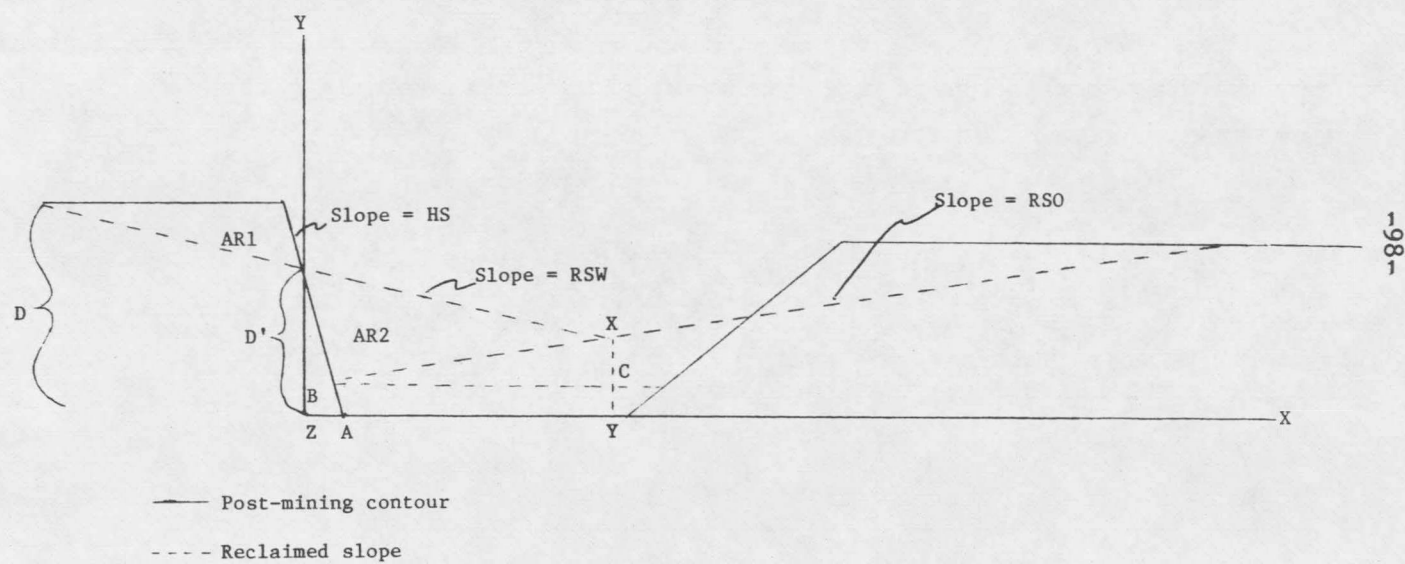
Other coordinates can also be found. The equation of the line representing the highwall slope is $Y = (HS)(X) + D'$

Setting $Y = H_1$ to find the coordinates of point B,

$$B \text{ coordinates } \left(\frac{H_1 - D', H_1}{-HS} \right)$$

The coordinates of Point X can be found with the use of the equations for the lines representing the reclaimed slopes on the highwall and spoil bank side of the highwall area. The equation for the line

Figure A.10. Labeled Cross-section Highwall Area



representing the reclaimed slope from highwall side is $Y = -RSW(X) + D'$ (Equation A.03). The equation for the line representing the reclaimed slope from the spoil bank side can be found because the coordinates of point B and the slope are known. The equation is $Y = (RSO)(X) + H1 - \frac{(RSO)(H1)}{HS} + \frac{(RSO)(D')}{HS}$.

Let $J = H1 - \frac{(RSO)(H1)}{HS}$. Then the equation for the line representing the reclaimed slope, spoil bank side is $Y = (RSO)(X) + J - \frac{(RSO)(D')}{HS}$, (Equation (A.04)). By solving Equations A.03 and A.04 simultaneously the coordinates of an expression for point X can be found.

$$\text{Let: } G = RSW - RSO$$

$$K = \frac{RSO}{(G)(HS)} - \frac{1}{G}$$

$$L = \frac{1}{RSW} - \frac{1}{RSO}$$

$$M = \frac{H1}{(HS)(L)} - \frac{H1}{(RSO)(L)}$$

$$N = \frac{1}{(RSW)(L)} - \frac{1}{(HS)(L)}$$

$$\text{Point X coordinates} = \left(\frac{J}{G} + (D')(K), M + (D')(N)\right)$$

Since X coordinates for points X, Y, and C are the same:

$$\text{Y coordinates equal } \left(\frac{J}{G} + (D')(K), 0\right)$$

$$\text{C coordinates equal } \left(\frac{J}{G} + (D')(K), H1\right)$$

An expression for AR2 can now be found.

$$AR2 = \text{area WXYZ} - \text{area WZA} - \text{area ABCY} - \text{area BXC}$$

$$\text{area WXYZ} = \frac{(D' + M + (D')(N))}{2} \left(\frac{J}{G} + (D')(K)\right)$$

$$\text{Let: } P = \frac{1 + N}{2}$$

$$\text{area WXYZ} = (P)(D') \left(\frac{J}{G}\right) + (P)(D')^2(K) + \frac{(M)(J)}{2G} + \frac{(M)(D')(K)}{2}$$

$$\begin{aligned}\text{area WZA} &= \frac{(D')}{2} \frac{(-D')}{HS} \\ &= \frac{-D'^2}{2HS}\end{aligned}$$

$$\begin{aligned}\text{area ABCY} &= \frac{(\overline{BC} + \overline{AY})}{2} (H1) \\ &= \left(\frac{J}{G} + (D')(K) - \frac{(-D')}{HS} + \frac{J}{G} + (D')(K) - \frac{H1}{HS} + \frac{(D')(H1)}{HS} \frac{2}{2}\right)\end{aligned}$$

$$\text{Let: } Q = \frac{(H1)(J)}{G} + \frac{H1^2}{2HS}$$

$$R = (H1)(K) + \frac{H1}{HS}$$

$$\text{Area ABCY} = Q + (D')(R)$$

$$\text{Area BXC} = \frac{(\overline{BX})(\overline{XC})}{2}$$

$$\overline{BC} = \frac{J}{G} + (D')^2(K) - \frac{H1-D'}{-HS} \overline{XC} = M + (D')(N) - H1$$

$$\text{Let: } S = M - H1$$

$$T = \frac{J}{G} + \frac{H1}{HS}$$

$$U = K - \frac{1}{HS}$$

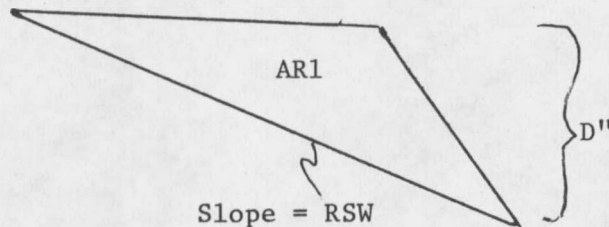
$$\text{Area BXC} = \frac{(S)(T)}{2} + \frac{(S)D'(U)}{2} + \frac{(D')(N)(T)}{2} + \frac{(D')^2(N)(U)}{2}$$

Now an expression can be found for AR2 in terms of D'.

$$\begin{aligned}\text{AR2} &= (P)(D') \left(\frac{J}{G}\right) + (P)(D')^2(K) + \frac{(M)(J)}{2G} + \frac{(M)(D')(K)}{2} + \left(\frac{-D'^2}{2HS}\right) - (Q \\ &\quad + (D')(R)) - \left(\frac{(S)(T)}{2} + \frac{(S)D'(U)}{2} + \frac{(D')(N)(T)}{2} + \frac{(D')^2(N)(U)}{2}\right)\end{aligned}$$

An expression can also be found for AR1 in terms of D'.

Figure A.11. Cross-section of Undisturbed Area to be Moved in Highwall Area.



Where: $D'' = D - D'$

$$AR1 = \frac{D''}{2} \left(\frac{D''}{RSW} - \frac{D''}{HS} \right) (-1) \quad \text{(Must be multiplied by -1 since RSW and HS are negative. Consult Figure A.11.)}$$

AR1 is the source of undisturbed overburden which will swell when moved to area AR2 (refer to Figure A.10). Therefore multiplying AR1 by a swell factor (SW) and substituting $D - D'$ for D'' ,

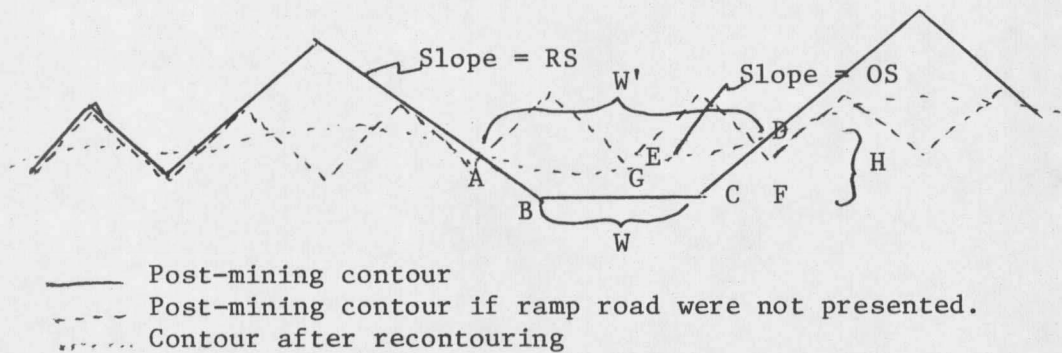
$$\text{Let: } V = \left(\frac{1}{RSW} - \frac{1}{HS} \right) (-1)$$

$$AR1 = \frac{(V)(D^2)(SW)}{2} - (V)(D)(D')(SW) - \frac{(V)(D'^2)(SW)}{2}$$

D' can now be found by setting $AR1 = AR2$ and solving. Substituting D' in the formula to find AR1 gives the area moved to recontour the highwall side of the highwall area. Multiplying AR1 by the variable labeled as ACRE in the model for the spoil bank side of the highwall area, gives the volume per acre to recontour the highwall side of the highwall area.

Method of Determining the Volume of Spoils Moved to Recontour the Ramp Road Area.

Figure A.12. Cross-section of Ramp Road.



Referring to Figure A.12, the known variables are:

H = average overburden depth or spoil bank depth to the bottom
of where the coal seam was present

W = width of the ramp road

OS = overburden slope

RS = reclaimed slope

AREA ABCDE = AREA 1 which is the area to be found or the area
which must be moved to produce the desired slope

AREA AED = AREA 2

AREA ABCD = AREA 3

If AREA 2 and AREA 3 are found, then AREA 1 can be found since:

AREA 1 = AREA 3 - AREA 2.

$$\text{AREA 3} = (W' + 2\overline{CF})$$

$$\text{OS} = H/\overline{CF}$$

Therefore:

$$\overline{CF} = H/\text{OS} \text{ and}$$

$$W' = W + 2H/\text{OS}.$$

AREA 3 can now be found.

$$\text{AREA 2} = \frac{(H')(W')}{2}$$

Since:

$$\text{RS} = \frac{H'}{2}$$

Therefore:

$$H' = (\text{RS})(W'/2).$$

AREA 2 can now be found and therefore AREA 1 can be found.

The width of the cross-sectional or ramp road area is equal to W' . The length of the area necessary to make an acre (ACRE) may be found since $\text{ACRE} = \text{area of an acre}/W'$.

ACRE timea AREA 1 yields the volume per acre of spoils moved to produce the desired slope.

Method of Determining the Volume of Spoils Moved to Recontour the Remaining Spoil Banks.

The spoil banks appear in either one of these general forms. If a standard pit width of 40 yards is assumed, then the spoil bank peaks

must also be 40 yards apart. If spoil banks have an 0.8 spope, then the spoil banks which have been produced from less than 5.12 yards of overburden will have a space between them (assuming a swell factor of 25%).

Figure A.13. Cross-section of Remaining Spoil Banks Produced from Less than 5.12 Yards of Overburden.

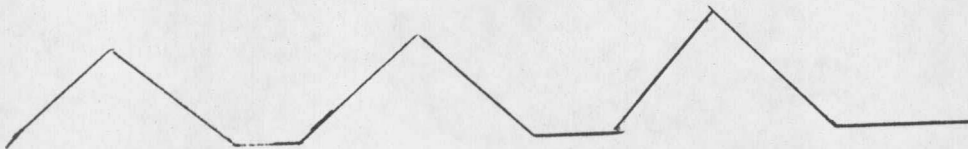
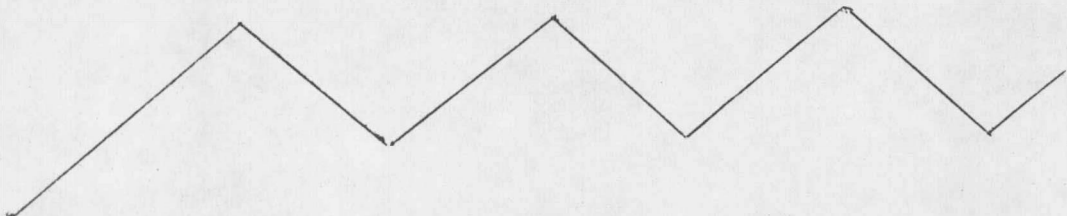
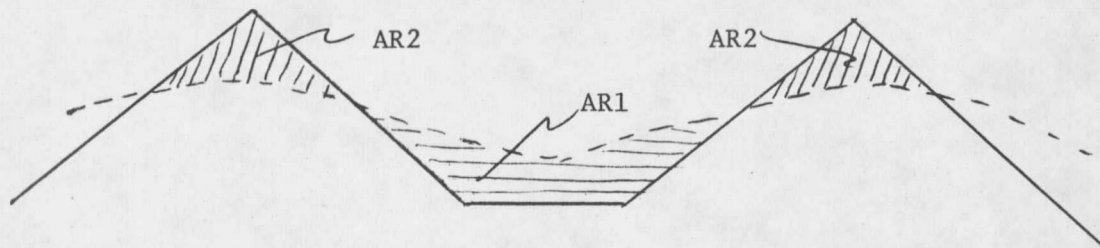


Figure A.14. Cross-section of Remaining Spoil Banks Produced from Greater than 5.12 Yards of Overburden.



Earlier in this section it was mentioned that one of the variables affecting the cost of recontouring the spoil banks was the volume, in cubic yards, of spoils to be moved.

Figure A.15. Cross-section of Remaining Spoil Bank Produced from Less than 5.12 Yards of Overburden showing Recontoured Slope.

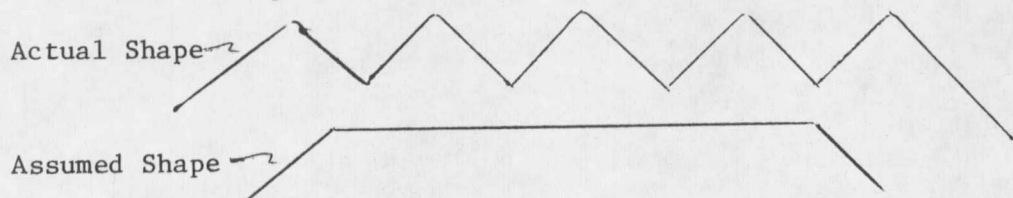


Post-mining contour

Reclaimed contour

The volume moved (vertically cross-hatched area, Figure A.15) is the volume to be filled (horizontally cross-hatched area). The yardage or volume moved may be calculated by finding the vertical area of the volume moved (vertically cross-hatched area) on a cross section and multiplying by the length of the spoil banks. The spoil banks must have a consistent shape for this model to hold true. Also, the model to calculate volume assumes that the tops of the spoil banks are level and not peaked as they are in fact. (Refer to Figure A.16.)

Figure A.16. Cross-section of Assumed and Actual Post-mining Contour of Remaining Spoil Bank Area



The volume of overburden moved when mining, multiplied by the swell factor, equals the volume of the spoil banks. Therefore, the area of the cross section of the spoil bank will be found as:

$$ARL = (D)(W)(SW + 1)$$

where:

ARL = area of the spoil banks

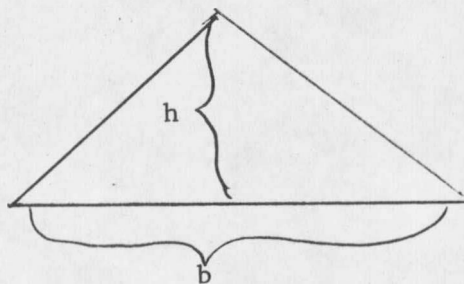
D = overburden depth

W = pit width

SW = swell factor.

The slope of the spoil banks are determined by physical characteristics of the material being stripped and spoil banked. Therefore, if the slope of the spoil bank is known, a relationship can be found between the height and the base of the spoil banks (refer to Figure A.17).

Figure A.17. Cross-section of a Spoil Bank.



$$OS = \frac{h}{\frac{b}{2}}$$

OS = slope of spoil banks

h = height of spoil banks

b = length of base

Therefore:

$$h = \frac{(OS)(b)}{2}$$

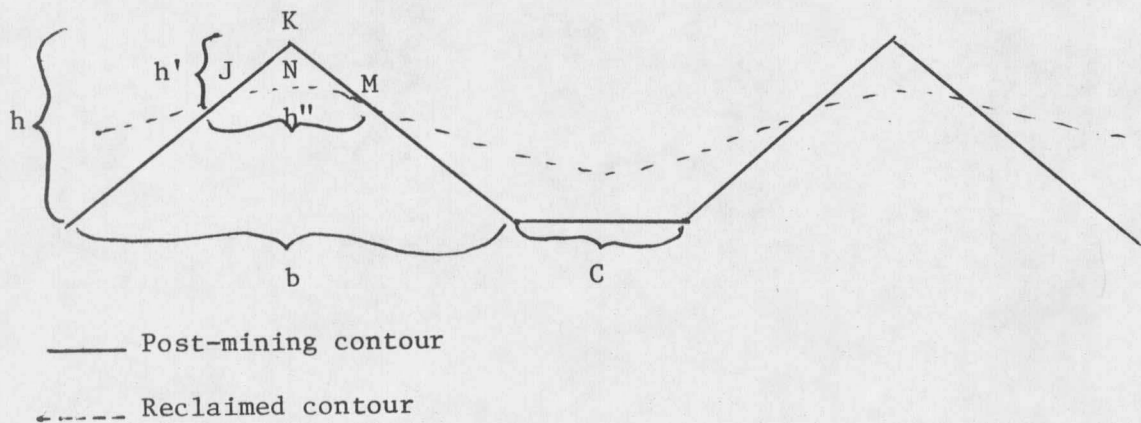
$$AR1 = \frac{(h)(b)}{2}$$

$$AR1 = \frac{(OS)(b^2)}{4}$$

Since AR1 is known, we let

$$b = \sqrt{\frac{4 AR1}{OS}}$$

Figure A.18. Labeled Cross-section of Remaining Spoil Bank Area.



The area of JKMN (area to be moved) is equal to vertically cross-hatched area in Figure A.15. Area of JKMN - triangle JKM-triangle JNM.

Allow h' to equal some value to be found. Let area JKM = AR2.

To find AR2 we must find b' .

$$OS = \frac{h'}{b'/2}$$

$$b' = \frac{2h'}{OS}$$

$$\begin{aligned} AR2 &= \frac{(h')(b')}{2} \\ &= \frac{h'^2}{OS} \end{aligned}$$

To find the area of JMN (hereafter referred to as AR3) h'' must be found. Assuming the reclaimed slope desired is known, then:

$$\begin{aligned} RS &= \frac{h''}{b'/2} & RS &= \text{reclaimed slope} \\ b' &= \frac{2h''}{OS} \end{aligned}$$

$$h'' = \frac{(H')(RS)}{OS}$$

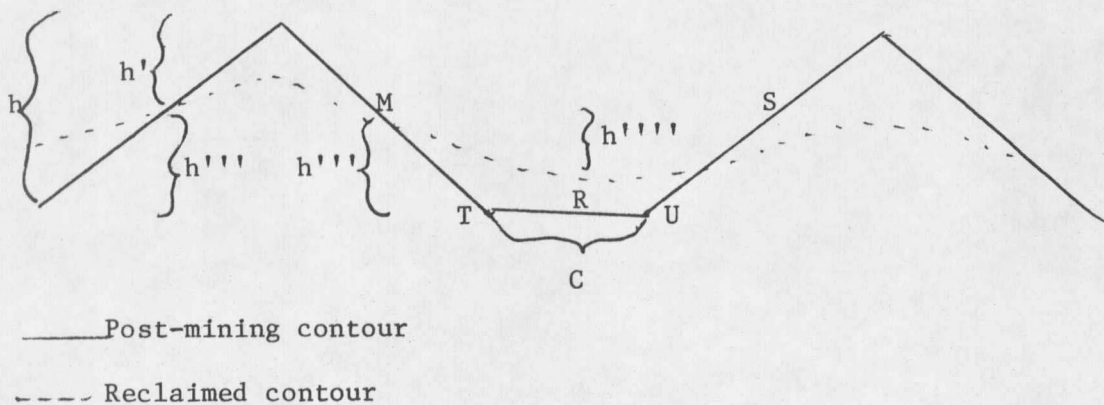
$$\begin{aligned} AR3 &= \frac{(h'')(b')}{2} \\ &= \frac{(h'')^2 (RS)}{OS^2} \end{aligned}$$

Let the area to be moved (JKMN) equal AR4.

$$\begin{aligned} AR4 &= AR2 - AR3 \\ AR4 &= \frac{h'^2}{OS} - \frac{(h'')^2 (RS)}{OS^2} \end{aligned}$$

$$AR4 = (A)(h'^2).$$

Figure A.19. Labeled Cross-section of Remaining Spoil Bank Area.



The area to be filled TMRSU (AR7) = area TMSU (AR5) - area MRS (AR6).

If expressions are found for AR5 and AR6, an expression can be found for AR7. (Refer to Figure A.19,)

We know: W = pit width

b = spoil bank base

$$h''' = h - h'$$

$$\text{Therefore: } AR5 = \frac{(C + \overline{MS})(h''')}{2}$$

Where: $C = W - b$

$$\overline{MS} = C + 2 \frac{h'''}{OS}$$

Therefore:

$$AR5 = (C)(g''') + \frac{h'''}{OS}$$

AR6 is a triangle.

$$AR6 = (C + \frac{2h'''}{OS}) \frac{(h''')}{2}$$

An expression for h'''' can be found.

$$RS = \frac{h''''}{C + \frac{2h''''}{OS}}$$

$$h'''' = \frac{(RS)(C) + \frac{2(h''')}{OS}(RS)}{2}$$

Substituting for h''''

$$AR6 = \frac{(RS)(C^2)}{4} + \frac{(C)(h''')(RS)}{2} + \frac{(h''')(RS)(C)}{2(OS)} + \frac{(h''')^2(RS)}{OS}$$

AR7 can now be found.

$$AR7 = AR5 - AR6.$$

$$= (C)(h''') + \frac{(h''')^2}{OS} - \frac{(RS)(C^2)}{4} - \frac{(C)(h''')(RS)}{2} - \frac{(h''')(RS)(C)}{2(OS)} \\ - \frac{(h''')^2(RS)}{OS^2}$$

Let"

$$D1 = C - \frac{(C)(RS)}{2} - \frac{(RS)(C)}{2(OS)}$$

$$E = \frac{1}{OS} - \frac{RS}{OS^2}$$

$$F = - \frac{(RS)(C^2)}{4}$$

$$\text{Then } AR7 = (h''')^2(E) + (h''')(D1) + F.$$

$$\text{Since } h''' = h - h',$$

$$AR7 = (h^2)(E) - 2(E)(h)(h') + (h'^2)(E) + (h)(D1) - (h')(D1) + F.$$

$$\text{Let: } G = (h^2)(E) + F + (h)(D1)$$

$$J = -2(E)(L) - D1$$

$$\text{Then } AR7 = (h'^2)(E) + (h')(J) + G.$$

Equating AR4, the area to be moved, with AR7, the area to be filled, then:

$$AR7 - AR4 = 0.$$

Substituting for AR7 and AR4

$$(h'^2)(E) + (h')(J) + G - (H)(h'^2) = 0.$$

Since $E = A$

$$(h')(J) + G = 0.$$

Therefore:

$$h' = -G/J \text{ and}$$

$$AR4 = (A)(h')^2.$$

The area to be moved, AR4, is known.

To convert this area to a per acre basis, the area of an acre is divided by the width of the pit.

Let:

$$ACRE = 4840/W$$

$$\text{Then: area of an acre} = (ACRE)(W)$$

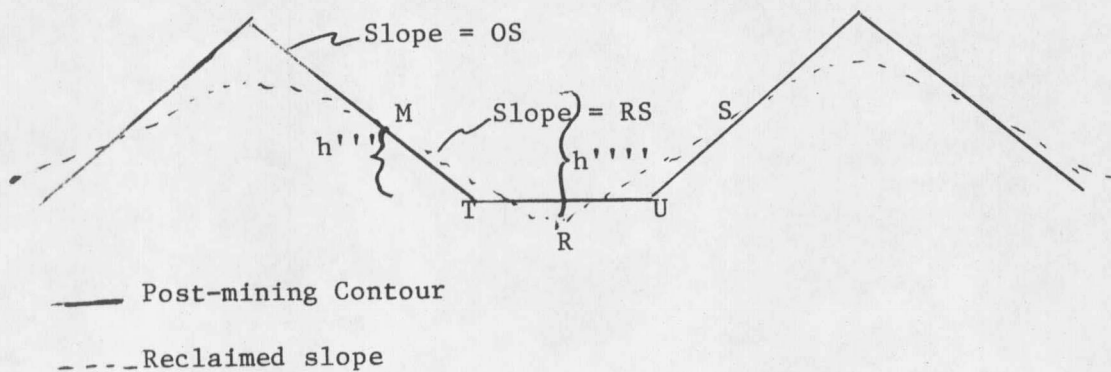
$$\text{When: } W = \text{pit width} - \text{distance between spoil bank peaks} = b + C$$

$$4840 = \text{square yards in an acre.}$$

Multiplying AR4 by ACRE generates the volume moved per acre.

If $h''' - h''''$ is less than 0 (as in Figure A.20), then h' is understated and so is AR4 and the volume per acre.

Figure A.20. Cross-section of Remaining Spoil Bank Area.



If h''' minus h'''' is less than 0, then adjustments must be made.
 The expression representing the area for AR4 remains the same, but the expression representing the area for AR7 changes.

$$AR7 = \frac{2(h''')(TR)}{2}$$

$$\text{Where: } h''' = h - h'$$

$$TR = \frac{h'''}{OS} - \frac{h'''}{RS}$$

$$\text{Let: } P = \frac{1}{OS} - \frac{1}{RS}$$

$$TR = (h''')(P)$$

$$\text{Therefore: } AR7 = (h''')^2(P)$$

$$\text{Put AR7 in terms of } h' \text{ (} h''' = h - h' \text{)}$$

$$AR7 = ((h^2)(P) - 2(h)(h')(P) + h'^2)$$

and set

$$AR4 = AR7.$$

$$0 = AR7 - AR4$$

Substituting for AR4 and A47

$$0 = (h^2)(P) - 2(h)(h')(P) + (h'^2)(P) = (h'^2)(A)$$

$$\text{Letting } X = P - A$$

$$Y = -2(h)(P)$$

$$Z = (h^2)(P)$$

Then solving for h'

AR4 can now be found.

$$AR4 = (h'^2)(A).$$

Proceed from here as before.

If the original spoil banks run together (refer to Figure 3.20), then

$$h = \frac{(OS)(W)}{2} \quad \text{because } OS = \frac{h}{\frac{b}{2}} \quad \text{and}$$

$b = W$ since the distance between spoil bank vees equals the pit width and $C = 0$ since there is no distance between the spoil banks.

The rest of the derivation is the same as before.

APPENDIX B

Appendix B

Generation of Machinery Cost Estimates for Revegetation.

Machinery cost estimates for September, 1972 are presented in Table B.01.

Table B.01. Machinery Cost Estimates for Seedbed Preparation, Seeding and Fertilizing (banding), and also Fertilizing (broadcasting).³⁶

<u>Machine</u>	<u>New Price</u>	<u>Performance Rate</u>	<u>Machine Life</u>	<u>Fuel & Lub. Cost/hr.</u>	<u>Repairs Cost/hr.</u>	<u>Labor³⁷ Cost/hr.</u>
Tractor 90HP (Diesel)	9600		12,000	0.86	1.15	4.00
Drill 12'	2100	2.8 A/hr.	1,000		1.84	
Tractor 55HP (Gas)	6200		12,000	1.08	0.74	4.00
Fertilizer Spreader 12'	380	2.8 A/hr. ³⁸	12,000		0.34	
Tandem Disc (12')	1200	5.6 A/hr.	2,000		0.53	

Updated machinery cost estimates may be produced by use of an appropriate inflationary factor. The appropriate inflationary factors are presented in Table B.02.

³⁶ Bucher, Dr. Robert F., Estimating Per Hour Operating Expenses of Farm Machinery, Montana Agricultural Experiment Station, Montana State University, Bozeman, Montana, September, 1972.

³⁷ Labor valued at \$4/hr.

³⁸ Performance rate for fertilizer spreader is assumed to be the same as that for the drill.

Table B.02. Inflationary Factor for Updating Machinery Cost Estimates.

<u>Indexes and Ratios</u>	<u>September 1972³⁹ Price Index</u>	<u>September 1974³⁹ Price Index</u>	<u>Inflationary Factor</u>
Farm Machinery	265	353	1.33
Motor Supplies	149	219	1.47

If the inflationary factor for farm machinery is applied to repair and original costs and for motor supplies is applied to fuel and lubrication costs, more up to date costs can be found. Multiplying the updated repair costs by four and dividing the machine life in half makes them pertinent to revegetation.⁴⁰ Depreciation expense per hour may be found by dividing the appropriate machine life into the updated new price. Ownership costs other than depreciation are estimated at 6% for interest, 0.6% for insurance, 1% for taxes, and 1% of the average value of the machine for housing. Ownership costs equal 8.6% of the average machine value or 4.3% of the new machine value plus depreciation expense.⁴¹ All costs may be put on a per acre basis by dividing the hourly operating costs by the performance rate. Per acre machinery cost

³⁹ News Release, Montana Crop and Livestock Reporting Service, USDA, Montana Department of Agriculture, Agricultural Statistic Reporting Service, Helena, Montana, December, 1974.

⁴⁰ Personal Interview, Hodder, Richard L., Reclamation Research, Montana State University, Bozeman, Montana, September, 1974.

⁴¹ Stevens, Delwin M. and Agee, Douglas E., Using Farm Machinery Efficiently, Bulletin 482, Agricultural Experiment Station, University of Wyoming, Laramie, Wyoming, December, 1967.

of revegetation are estimated in Table B.03.

Table B.03. Estimated Per Acre Machinery Costs for Revegetation.

<u>Activity</u>	<u>Ownership⁴² Cost/A.</u>	<u>Fuel & Lub. Cost/A.</u>	<u>Repair Cost/A.</u>	<u>Labor Cost/A.</u>	<u>Activity Cost/A.</u>
Seed Bed Preparation	1.47	0.28	1.24	0.71	3.70
Seeding and Band Fertilizing	7.83	0.45	5.68	1.43	15.39
Broadcast Fertilizing	1.62	0.57	2.12	1.43	<u>5.74</u>
Total Costs					24.83

Machinery cost estimates for planting trees are presented in Table B.04 (tractor estimates are updated from September, 1972 and post hole digger estimates are current).

Table B.04. Machinery Cost Estimates for Tree Planting (Tublings).

<u>Machine</u>	<u>New Cost</u>	<u>Performance Rate</u>	<u>Machine Life</u>	<u>Fuel & Lub. Cost/hr.</u>	<u>Repairs Cost/A.</u>
Tractor 40HP (Gas)	6517 ⁴³		12,000 ⁴³	1.25 ⁴³	3.18 ⁴³
Post Hole	463 ⁴⁴	12 holes/hr ⁴⁵	5,000holes ⁴⁶		0.24 ⁴⁶

⁴² 450 acres/year are assumed to be reclaimed for purposes of estimating per acre ownership costs.

⁴³ Bucher, Dr. Robert F., Estimating Per Hour Operating Expenses of Farm Machinery, Montana Agricultural Experiment Station, Montana State University, Bozeman, Montana, September, 1972.

The machinery cost of planting tublings without plastic aprons is the same as planting those with plastic aprons. While plastic aprons are installed, machinery is not used. No machinery is used to plant seedlings. Using the methods presented in the previous section (Machinery Cost Estimates for Seeding and Fertilizing (banding and broadcasting)) the cost estimates presented in Table B.05 can be found.

Table B.05. Estimated Machinery Cost Per Tubling Planted.

<u>Activity</u>	<u>Ownership⁴⁷</u> <u>Cost/Tree</u>	<u>Fuel & Lub.</u> <u>Cost/Tree</u>	<u>Repairs</u> <u>Cost/Tree</u>	<u>Total</u> <u>Cost/Tree</u>
Planting a Tubling	0.25	0.11	0.28	0.64

⁴⁴ Personal Interview, Gallatin County Equipment, Bozeman, Montana, January, 1975.

⁴⁵ Telephone Interview, Hodder, Richard L., Reclamation Research, Montana State University, Bozeman, Montana, February, 1975.

⁴⁶ Labor valued at \$4/hr.

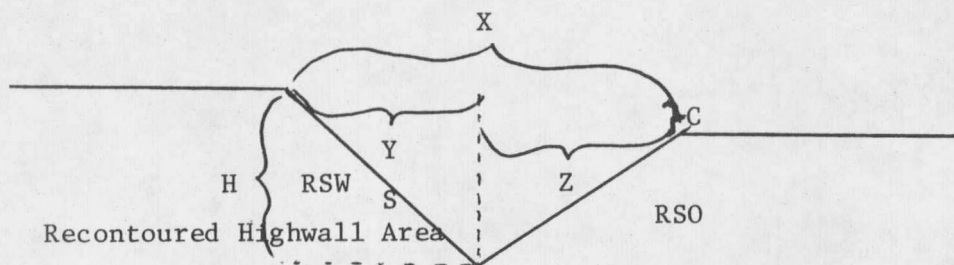
⁴⁷ 2500 tublings/year are assumed to be planted for purposes of estimating ownership costs per tubling planted.

APPENDIX C

Appendix C

Method of Determining the Length of the Recontoured Slope on the
Highwall Side of the Highwall Area.

Figure C.01. Diagram to Determine Width of Recontoured Slope on the
Highwall Side of the Highwall Area.



Knowns:

X = highwall area width
C = highwall height - average spoil bank depth
RSW = reclaimed highwall slope
RSO = reclaimed slope opposite the highwall
H = highwall height

Let:

Y = length of the recontoured slope on the highwall side (the
distance to be found)

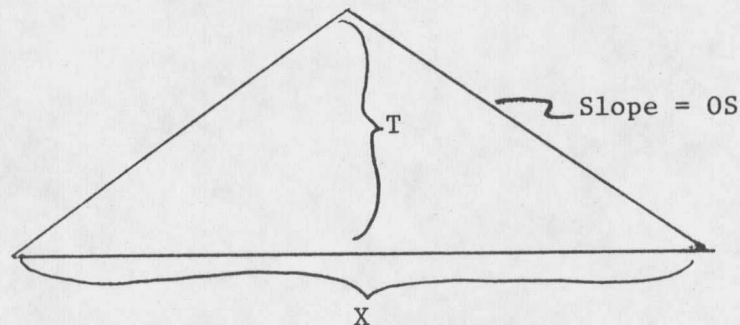
$$\begin{aligned} X &= Z + Y \\ Z &= X - Y \\ RSW &= H/Y \\ RSO &= (H - C)/(X - Y) \\ H &= RSO (X - Y) + C \\ H &= Y(RSW) \\ Y(RSW) &= RSO(X) - RSO(Y) + C \\ Y &= (RSO(X) + C)/(RSW + RSO) \end{aligned}$$

H should be computed and compared to actual highwall height. If H is greater than the actual highwall height, then H should be set equal to the highwall height and $Y = H/HS$.

Method of Determining Average Push Distance in Ramp Road Area.

The push distance of the bulldozer may be estimated by averaging the longest and shortest push distance. Assume that the overburden displaced by the ramp road is placed on both sides of the ramp road. The shortest push distance is the minimum and the longest push distance is $1/2$ the width of the ramp road area plus the width of the area occupied by the yardage displaced by the ramp road.

Figure C.02. Cross-section of the Yardage Displaced by the Ramp Road.



T = height

X = base

OS = overburden slope

AREA 4 = $(T)(X)/2$

AREA 4 - AREA 3/2

AREA 3 is known

$T = (OS(X))/2$

(AREA 4 and AREA 3 are estimated

in procedures in Appendix A, Method

of Determining the Volume of Spoils

Moved to Recontour the Ramp Road Area)

$$\begin{aligned} \text{AREA 4} &= \frac{(\text{OS})(X)(X)(1/2)}{2} \\ &= \frac{(\text{OS})(X^2)}{4} \\ X &= \frac{(4)(\text{AREA 4})^{1/2}}{\text{OS}} \end{aligned}$$

The longest push distance equal $W'^{48}/2 + X$ or $1/2$ the width of the ramp road area plus the base of the displaced yardage. The average push distance is approximated by averaging the shortest push distance (minimum push distance) and the longest push distance ($W'/2 + X$).

⁴⁸W' can be found by the method presented in Appendix A, Method of Determining the Volume of Spoils Moved to Recontour the Ramp Road Area.

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Watts, Myles J

Estimated costs of
spoil bank reclamation
alternatives

DATE	ISSUED TO
	Ray Beck 3000 Volume Helena MT Dept State Land 449-2074 Capital
	Bruce Carrigan 105 S Julia
1991 9	Lady Dress Wages Note
2 WEEKS	USE ONLY
	REPAIR
1992 3	Robt. 20
R	F

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