DESIGN CRITERIA FOR A SURFACE COAL MINE RECLAMATION PLAN IN NORTHWEST COLORADO

by

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Throughout my life, my friends and family have provided a special type of encouragement which will not cease to help me smile in future days. To Dave and Lynn, Bruce and Chris, Wally and Karen, Paul, Rick, and Nancy and Alan Marston I owe thanks for showing me what is truely important in life. The following pages are dedicated to them.

Finally, I would like to express my gratitude to Laura Cole for her cartographic assistance and to Luanne Beller for typing.

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There's a lot of things I don't like about my work. I've never really appreciated seeing ground tore up. Especially if that ground could be made into something. I think about it all the time. You tear somethin' up that you know has taken years and years and years... and you dig into rock. You get to talkin' about the glacier went through there and what caused this particular rock to come out of the bank like it does. You see things come out of that bank that haven't been moved for years. When you see 'em, you have to think about 'em.

- Strip Miner in Working,
by Studs Terkel

DESIGN CRITERIA FOR A SURFACE COAL MINE RECLAMATION PLAN IN NORTHWEST COLORADO

ABSTRACT: The surface mining of coal has accelerated in northwest Colorado to the point where public pressure plus impending state and federal regulations dictate the need for comprehensive reclamation plans. A large coal company operating in Moffat County has solicited recommendations concerning soils, hydrogeology, geomorphology, aesthetics, wildlife, vegetation, microclimatology, and legal aspects of reclamation problems with the intent of restoring rangeland suitable for grazing with wildlife habitat important to the region's recreation-derived revenue. Specific recommendations have been presented which realize the practical limits of operating procedures affecting the handling of topsoil and overburden, the design of roads, and the nature and shape of the final recontoured landscape.

INTRODUCTION

The scope of a "reclamation" plan for a surface coal mine involves all physical, aesthetic, and legal parameters which have weight in creating a stable recontoured landscape.

Together with revegetation studies which focus on the biological suitability of various plant species, a total "rehabilitation" plan may be compiled for submission to the appropriate state and federal agencies as part of the permit process. The success of any reclamation plan has been shown to depend heavily on the degree to which the individual coal company recognizes and addresses the problems of instability and then incorporates serious reclamation efforts into their budget. These efforts contrast between the two active mines studied in northwest Colorado and have been very influential in the derivation of the reclamation plan for the proposed Colowyo Mine.

In June, 1974, W.R. Grace and Company released the Draft Environmental Impact Statement for the Proposed Colowyo Mine in Moffat County, Colorado.[1] In late 1974, a supplementary study was begun under the direction of the Colorado State University Department of Plant Science to investigate the potential suitability of utilizing native species of browse plants for the revegetation of the Colowyo Mine site. It soon became apparent that input was required pertaining to the non-biological aspects of rehabilitating the mine site in order to provide the ecological requirements of the browse species tested while simultaneously creating a stable hydrologic and slope regime. Hence, a proposal was submitted to W.R. Grace and Company by V.T.N. Architects-Engineers-

Planners in Denver, Colorado, to complement the revegetation program with a reclamation plan involving eight disciplines: pedology, wildlife, vegetation, hydrogeology, geomorphology, microclimatology, aesthetics, and law. The author participated in the reclamation project for the Colowyo Mine, contributing the sections on geomorphology and aesthetics.

The Grace Reclamation Project necessitated field work in August, 1974 and again in August and September, 1975 at the Colowyo Mine site and at the active Energy Fuels and Edna Mines in adjacent Routt County. The perspective provided by observing the contrasting efforts towards reclamation by the two nearby mines provided extensive insight to the problems inherited at the Colowyo Mine under similar geographic conditions. Work in the field was supplemented by an extensive literature search and interviews with several mining engineers and well as state and federal government reclamation specialists. Extensive interaction with other project members of V.T.N. was also productive, culminating in the report released in February, 1976, The Reclamation Plan for the Proposed Colowyo Mine.[2]

The purpose of the following pages is threefold. First, the state-of-the-art in reclamation of surface coal mines in northwest Colorado will be summarized with an emphasis toward pointing out the contrasting efforts by two coal companies. Second, a discussion will be presented on the steps followed in the derivation of a detailed reclamation plan, focusing on the key legal and physical geographic components. Third, specific recommendations will be forwarded for the reclamation plan to be submitted for the Colowyo Mine by W.R. Grace and Company. The recommendations involving the aesthetic resources and geomorphology of the reclamation plan will be most thoroughly scrutinized. The lasting intent of this paper is to provide source material and a logical framework for compilation of a reliable and comprehensive reclamation plan.

SURFACE COAL MINING IN NORTHWEST COLORADO

Three surface coal mine sites in northwest Colorado were studied in order to become familiar with current reclamation techniques and problems (Figure 1). The two active mines are the Edna Mine, owned by Pittsburgh and Midway Coal Company, and the Energy Fuels Mines, owned by the Energy Fuels Corporation. Both are located eleven to twelve kilometers (eighteen to twenty miles) southwest of Steamboat Springs in Routt County, Colorado on County Road 27, also known as Twenty Mile Road. The Colowyo Mine, owned by W.R. Grace and Company is located approximately fifteen kilometers (twenty-four miles) south of Craig in Moffat County, Colorado, adjacent to

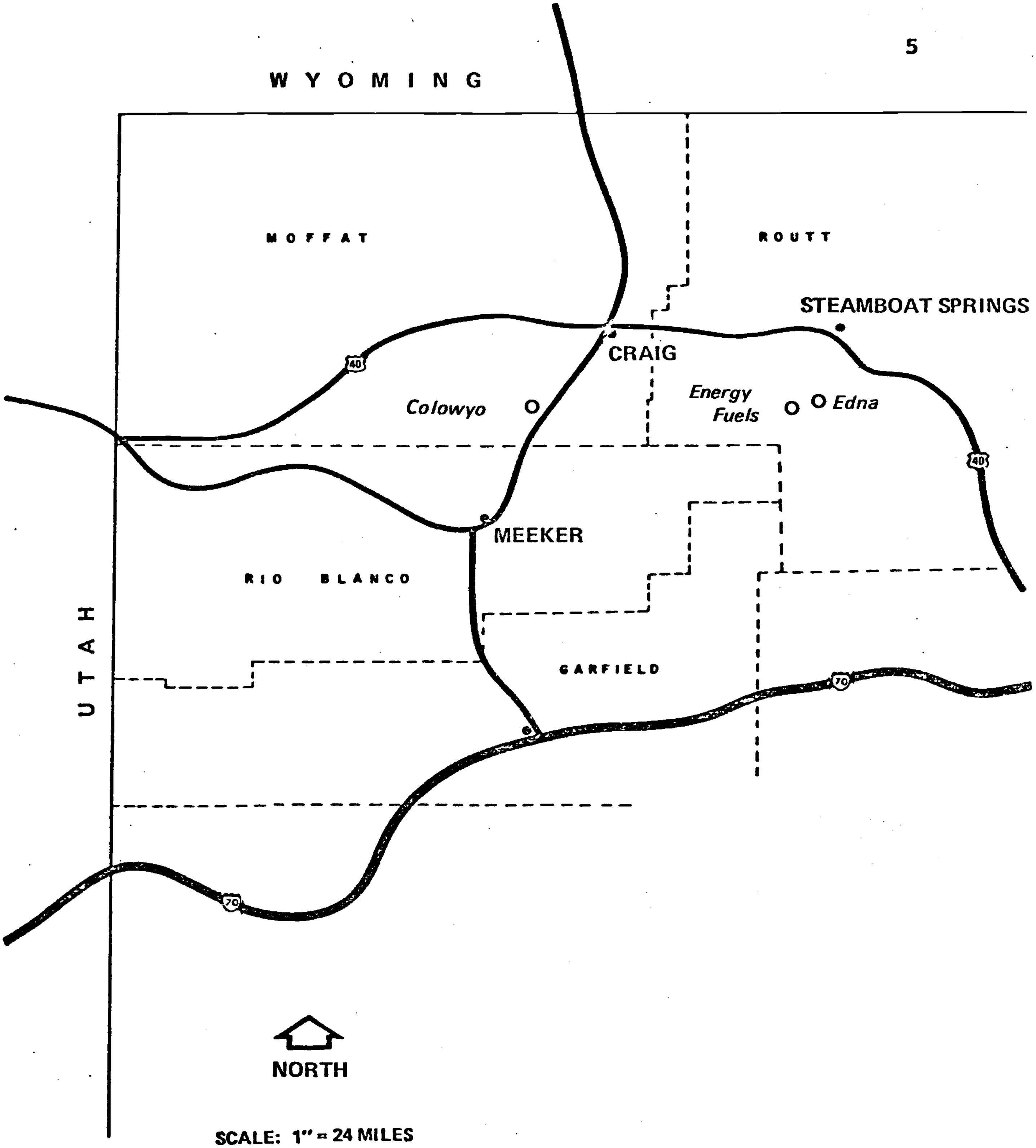

Figure 1. Location of three surface coal mines studied in northwest Colorado. Source: V.T.N. Engineers-Architects-Planners, op. cit., footnote 1, p. 10.

Colorado State Highway 13. As of March, 1976, surface mining has not yet begun at the Colowyo Mine site.

Reclamation at the Edna Mine

The Edna Mine lies at elevations between 2160 and 2380 meters (7100 and 7800 feet) and is subject to 51 cm (20 inches) mean annual precipitation, of which approximately one-half is snow. The potential evapotranspiration, however, is 93 cm (37 inches). The total disturbed area of the Edna operation is 597 hectares (1475 acres) which constitutes four percent by area of the Trout Creek Watershed, yielding some 2.8×10^7 m^3 (23 acre-feet) per year.[3] Eventually, the Edna mining operations will have disturbed 1296 hectares (3200 acres). To date, 243 hectares (600 acres) have been "reclaimed" to the extent expected, according to the mining engineer at Edna who led the author on a tour of the mine on September 12, 1975. Mine production at present averages 1.0 to 1.2 million tons per year, expected to be sustained for 14½ more years (1990).[4]

Coal at the Edna Mine lies in the "Wedge Seam" of the Williams Fork Formation which dates to the Upper Cretaceous (Figure 2). The overburden is composed of shales and sandy shales with alternating thin sandstone beds. The strata and topography dip to the west at approximately ten percent and the strike is to the

GENERALIZED STRATIGRAPHIC COLUMN
in vicinity of
MOUNT STREETER, MOFFAT COUNTY, COLORADO

ERA	PERIOD	TIME ($x10^6$ yrs ago)	GROUP	FORMATION	MEMBER	SUMMARY LITHOLOGIC DESCRIPTION	APPROXIMATE THICKNESS IN FEET: UNIT	APPROXIMATE THICKNESS IN FEET: CUMULATIVE
		70						
MESOZOIC	Cretaceous Upper		Mesa Verde Group	Williams Fork Formation		Alternating sandstone, sandy shale, carbonaceous shale, and coal beds; characterized by brick-red color.	1000	1000
			Mesa Verde Group	Iles Formation	Trout Creek SS member	Sandstone, white, fine-grained, well sorted, massive, fairly uniform in thickness.	100	1100
			Mesa Verde Group	Iles Formation		Alternating beds of massive sandstone and sandy or carbonaceous shale; light brown to white, poorly sorted, generally calcareous, grades into coal.	1300	2400
				Mancos Shale		Clay shale; soft dark-gray to drab, with lenses and interbeds of sandstone as much as 75 feet thick. Basal unit of bluish and dark-gray slaty shale and calcareous sandstone.	5600	8000
		unconformity		Dakota Sandstone (?)		Quartzitic sandstone; thinly banded greenish-gray, with pebbles at the base.	260	8260
	Jurassic Upper			Morrison Formation		Shale, limestone, chert, conglomerate lenses, and sandstone; green, greenish-gray, varicolored and maroon.	400	8600
			San Rafael Group	Curtis Formation		Shale, glauconite sandstone and thin beds of glauconitic limestone, locally oolitic, thinly-bedded, gray.	40	8700
		unconformity	San Rafael Group	Entrada Formation		Sandstone; massive beds, fine-grained, sugary, light gray.	400	9100
	Triassic Upper			Chinle Formation		Calcareous shale, mudstone and a few sandstone and limestone pellet conglomerate beds.	350	9450
		unconformity		Shinarump Conglomerate		Sandstone and conglomerate interbedded, lenticular beds and steeply crossbedded, red.	50	9500
	Triassic Lower			Moenkopi Formation		Siltstone, shale; greenish-gray and gray, with thin red colored beds.	600	10100
		225						
PALEOZOIC	Permian			Phosphoria Formation		Calcareous shale to sandstone, limestone, and chert with concretions.	100	10200
		270						
	Pennsylvanian			Weber Sandstone		Calcareous sandstone; massive, light gray to buff, fine-grained.	250	10450
				Maroon Formation		Shale, sandstone, and limestone; red, interbedded.	1150	11600
				Paradox Formation		Gypsum, dark shale, yellow sandstone, red shale and siltstone; thick beds.	650	12250
		unconformity		Morgan Formation		Cherty sandstone, shale and limestone.	1750	14000
	Mississippian			Molas (?)		Basal red shale of Morgan Formation.	50	14050
				Madison Limestone		Cherty dolomitic limestone and dolomite; light and dark gray.	430	14480
	? — ?	350?						
	?	unconformity		Beds of undetermined age		Interbedded shale sandstone, limestone an dolomite.	200	14680
	Cambrian			Sawatch Quartzite		Dolomitic quartzite to quartzose sandstone; dark to very light brown and gray, locally crossbedded.	?	?
		570						

Figure 2. Generalized stratigraphic column in vicinity of Mount Streeter, Moffat County, Colorado. The Trout Creek Sandstone member of the Iles Formation is the lower marker for the coal seams of concern. Source: V.T.N. Engineers-Architects-Planners, op. cit., footnote 1, p. 34.

northeast parallel to Trout Creek which flows at the foot of the mined slope. Trout Creek is the major drainage at the site and exists in an alluvial aquifer. Otherwise, groundwater is limited to fracture storage which is fortunate in that seepage into the open pit is not a problem.

Overburden stripped during the initial mining period from 1947 to 1962 were placed in spoil piles over undisturbed ground. Although peaks on these older spoils have been "knocked-off", sediment yield and release of soluble salts remains a problem. Revegetation was attempted with aerial seeding with poor results (Figure 3 and 4). During the tour of the Edna Mine, the mining engineer mentioned that in the near future these spoilpiles may be removed in order to surface mine the undisturbed land to a deeper coal seam. Mining with the strike has proceeded upslope such that the spoil ridges are aligned parallel to the strike and thus parallel to Trout Creek (Figure 4).[5] Slope exposure on the recontoured landscape is dictated by the regional geologic uplift culminating in short, steep east-facing slopes and lengthy but shallow west-facing slopes. However, the alignment of spoil ridges parallel to the strike of the slope has required drainage diversions as a consequence.

No attempt was made at the Edna Mine to store topsoil, although the mining engineer indicated such efforts would be forthcoming if necessitated by legislation.

Figure 3. Upgraded spoils at the Edna Mine stockpiled between 1947 and 1962. Notice the road across the spoil piles which are approximately twelve meters (40 feet) high. Source: Photo by author.

Figure 4. View of Edna Mine showing regarded spoils (far left), upgraded spoils aligned with dip of slope, and same spoils shown in Figure 3 (far right center). Source: Photo by author.

Initial compaction of the regraded spoils was so great that revegetation by aerial seeding failed as no mulches or fertilizers were used. Vegetation is sparse and unattractive, consisting primarily of Russion thistle with clover in isolated cases. Elsewhere, poor compaction has predicated settling which is evidenced by a cracked surface, prohibiting vegetation and enabling erosion. The regraded spoils have produced both more surface runoff and more infiltration than the original topography in areas with little vegetation. Where a reasonable vegetative cover has been achieved, runoff has subsided to a greater degree than infiltration. The Edna mining engineer recommended that construction of steep southwest and south-facing slopes on the recontoured surface should be avoided because of poor moisture retention and high ground temperatures, occasionally approaching 120° F. Slopes with gradients less than ten percent are preferred on these aspects to avoid excess surface runoff. It was also reported that it takes approximately eight years to produce a "soil-like" substance on the Edna regraded spoils, with the largest contribution coming from fine-sized particles derived from the rapid disintegration of shales.[6]

The main contribution to sediment yield has been material released through open cuts since no sediment retention basin of any type is employed aside from a berm placed adjacent to Trout Creek. The sediment problem on the Edna regraded landscape is partially alleviated by construction of an undulating topography which captures sediment and runoff in small basins. Accordingly, the release of soluble salts to Trout Creek has also been a problem, documented in a study by the Environmental Protection Agency, Water Quality Control in Mine Spoils - Upper Colorado River Basin, published in June, 1975. Soluble salts have been flushed from the clay material in the spoils where cation exchange with sodium, calcium, magnesium, sulfate, and bicarbonate has occurred. In thirty-four samples from twelve locations, soluble salts were produced at a rate of 2.4 kilograms per cubic meter. In nine months, 6187 metric tons (6700 tons) of soluble salts were absorbed by Trout Creek. Eighty percent of this release occurred during the runoff from snow-melt in April, May, and early June when infiltration capacity is exceeded. The estimated average yearly release from the Edna Mine is 5.5 metric tons per hectare (2.4 tons per acre) of soluble salts. This is ten times the amount contributed by the upstream portion of the Trout Creek watershed.[7] It is interesting to point out that the Edna mining engineer felt that the contribution of soluble salts to the Colorado River System will be the main deterrent to the surface mining of coal in the Western United States in the next ten years.

Reclamation at the Energy Fuels Mines

The Energy Fuels Corporation actually operates three separate mining areas in close proximity to each other but with slightly differing geographic settings. Consequently, each area inherits a set of reclamation problems and has a distinct proposed land use once all mining has ceased. For Energy 1, the proposed land use is grazing for wildlife and domestic livestock. Energy 2 will be used for planting of small grain crops, and Energy 3 will support either farmland or rangeland, as yet not decided. The author was led on a tour of all three mining areas by Duane Johnson, an aquatic biologist and reclamation specialist who directs all reclamation efforts at the Energy Fuels Mine. Each year, a total of 122 hectares (300 acres) have been disturbed for the three mines, soon to reach 202 hectares (500 acres) per year.

Energy 1 lies at elevations between 2103 and 2316 meters (6900 and 7600 feet) and is the oldest mine area with spoils derived from mining in 1962. The majority of the 30 to 51 centimeters (15 to 20 inches) of precipitation occurs as snow, supporting a mountain shrub community and abandoned grain fields. Draglines remove the overburden after blasting after which it is sidecast into spoilpiles to be regraded to the approximate original contour. Mining operations at the Energy Fuels Mine prior to passage of the 1974 Colorado Open Mining Land Reclamation Act included placement of spoilpiles parallel to the dip of the slope which caused excessive sediment and soluble salt releases.[8] When the topsoil is redressed on north-facing slopes, it is shaped, disced, harrowed, and seeded. The Energy Fuels Corporation has shown regard for aesthetic attributes of the area by attempting to transplant small stands of aspen. This has met with an eighty percent success rate, hampered by snow accumulation on these north slopes, despite planting of trees with a fifteen centimeter (six inch) diameter at breast height. To encourage root growth, branches are trimmed back and guy wires are used to stabilize the trees. It should be noted that on-going reclamation work at Energy 1 is voluntary on the part of Energy Fuels Corporation as mining began prior to passage of the state statute.

Energy 2 lies at elevations between 2042 and 2134 meters (6700 and 7000 feet) on a west-facing slope rising from the east bank of Fish Creek. The site receives an identical amount of precipitation which promotes a sagebrush community on shallow clay soils (Figure 5). Mining was started in 1972 and most of the stockpiles have been leveled. The spoils are shaped to the original contour and compacted to reduce infiltration.[9] The most impressive aspect of Energy Fuels' reclamation efforts was their use of four elevation ("paddlewheel") rubber-tire scrappers, each with a 17 cubic meter (32 cubic yard) capacity, capable of removing two inch layers of soil (Figure 6). The upshot has been the ability to actually separate the topmost soil horizons found at the site. These are stockpiled separately and replaced in reverse order as they were removed. Duane Johnson pointed out that the best time to replace topsoil is between May and November because the soils have dried sufficiently by that time. The topsoil is smoothed, disced, harrowed, and reseeded. Drill seeding is preferred because it is possible to deposit the seeds directly into the ground whereas areal seeding requires three to four times as much seed. Local farmers can be contracted for the drilling and seeding. After growth has been established on the regraded landscape, Johnson recommends that two or three years be allowed to pass before active grazing begins in order to provide for adequate protection against erosion from trampling. There is a problem at Energy 2 with groundwater seepage into the pit. The Environmental Protection Agency has required that this groundwater be pumped into an evaporation pond rather than straight into Fish Creek.[10]

Energy 3 lies at elevations between 2012 and 2103 meters (6600 and 6900 feet) and receives the same range of precipitation as do the other two Energy Fuels' mines. At the time of the tour in September, 1975,

Figure 5. Aerial view of Energy 2 Mine showing open cut, spoil piles, and reclaimed surface sloping to Fish Creek. Source: Photo by author.

Figure 6. Paddlewheel scrappers removing topsoil at Energy 3 Mine. Source: Photo by author.

coal had been mined for one year and portions of the disturbed surface had already been reclaimed. A horse was observed grazing on grasses planted in spring, 1975, far too early for adequate establishment of a protective vegetative cover. Again, there has been a problem with spring runoff from snowmelt entering the pit such that pumping was required. For both Energy 2 and Energy 3, the time lag between stripping and reclamation is approximately one year.[11]

The reclamation efforts of the Energy Fuels Corporation are to be commended, although Duane Johnson asserted that there was room for considerably more innovation. In contrast to the Edna Mine, Energy Fuels had drill seeded, stockpiled topsoil, segregated soil horizons, and practiced more effective controls over the discharge of sediment and soluble salts from distrubed lands. Mr. Johnson indicated that feedback from other coal companies operating in northwest Colorado has been negative in that their reclamation plans are put in a bad light when compared to the Energy Fuel's plan. Finally, Mr. Johnson talked of the practical problems of implementing his recommendations during the actual mining operations. Holding the rare position as a full-time reclamation engineer, he has to be able to communicate his intentions to the mine foreman and to the equipment operators who traditionally have little appreciation for preserving thin layers of topsoil.

His suggestions along this line have been incorporated into the design and layout of the reclamation plan for the Colowyo Mine.

THE DERIVATION OF THE COLOWYO MINE RECLAMATION PLAN

The Colowyo Mine lies at elevations between 2134 and 2317 meters (7000 and 7600 feet) in a topography characterized by gentle northerly-sloping mesas. Stream incision along Streeter Draw and the tributaries of Good Springs Creek on the mine property has resulted in steepwalled canyons (Figure 7). Existing clayey-loam to sandy-loam soils range in depth from 50.8 to 101.6 centimeters (20 to 40 inches), with an average organic matter content of only five percent. Fracture storage constitutes the only source of groundwater as there are no major aquifers on the mine property. Streeter Draw and the tributaries of Good Springs Creek are the only watersheds to be directly altered by the mining operation, all supporting ephemeral flows. A total of 40.6 to 45.7 centimeters (16 to 18 inches) of precipitation can be expected each year, typical of the semi-arid climate in the western slope region of northwest Colorado. Snowfall accounts for at least one-half of this total, occurring between October and May. Sagebrush steppe, brush communities, and pinyon-juniper woodland are present

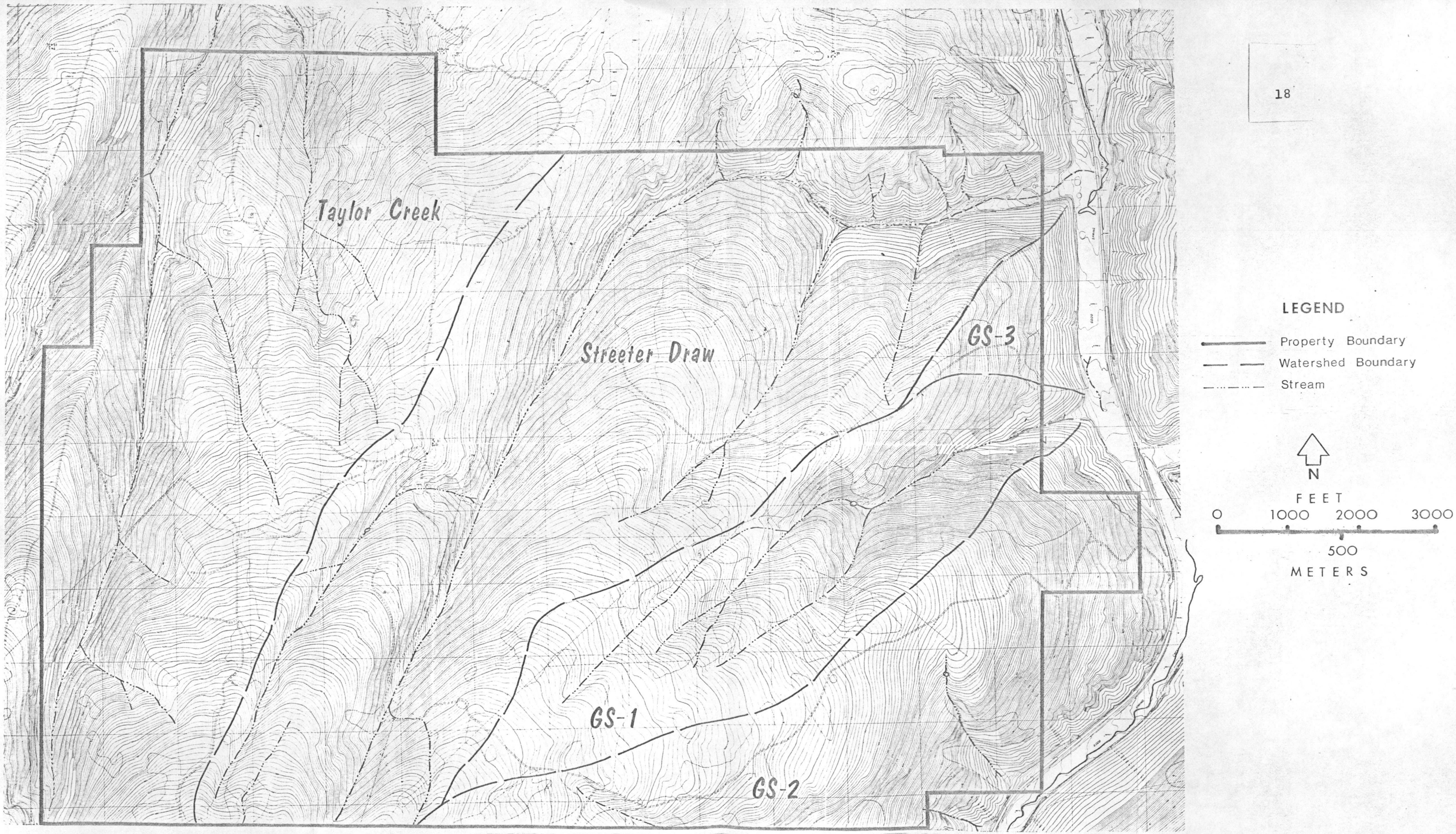

Figure 7. Map of existing topography and watershed boundaries at the Colowyo Mine. The mining zone is bounded by the creek in Streeter Draw and the south, east, and north property lines. Source: Prepared by author.

on the site, affording habitat for three big game species, deer, elk, and antelope.[12] Recreational hunting is the major economic stimuli for the region with a total of 201967 hunter-days in 1974 in a three-county area in northwest Colorado. Of this total, only thirty-five percent of the hunting occurred on public lands, reflecting the interest in hunting on private property, true for the Colowyo Mine.[13]

A fairly thorough environmental impact statement was prepared for the Colowyo Mine in June, 1974 by V.T.N. for W.R. Grace and Company. Upon a change in the original mining plan, a revised E.I.S. was released in late 1975. These reports present a detailed description of the existing environment and associated physical, biological, and social impacts incurred from the mining operation. However, only three paragraphs are devoted to the "Proposed Reclamation Plans". The upshot of the 1974 Colorado Open Mine Land Reclamation Act has been to allow the State Land Reclamation Board to establish guidelines for the preparation of a detailed reclamation plan, subject to their approval. W.R. Grace and Company has fulfilled this requirement through the submission of the reclamation plan prepared by V.T.N.

The reclamation plan for the Colowyo Mine was based on four goals, each recognized as a key element to a comprehensive plan. First, the reclamation plan must necessarily be incorporated into the mining plan. Because reclamation efforts at the Colowyo Mine will be continual throughout the operation, the practical limits of mining equipment and practices must be reconciled with the recommendations promoting environmental stability.

The second key element of the reclamation plan for the Colowyo Mine is the interdisciplinary approach seen as necessary to fully understand the complexities in formulating a physically stable recontoured surface. The recommendations must be consistent with all legal requirements and the desired future land use for the mine property after the mining and reclamation has ceased. The V.T.N. personnel chosen to compile the reclamation plan for the Colowyo Mine provided input for specific recommendations pertaining to wildlife, vegetation, soils, hydrogeology, climatology, aesthetics, geomorphology, and legal considerations.

The third focus of the reclamation study was to identify and articulate the possible hazards imposed by the tremendous environmental impacts caused by the surface mining and reclamation activities. The mitigation of these hazards was the gist of the interaction of the various project team members. Under the guise of wildlife management, species requirements must be delineated, as well as deciding upon methods of removing existing wildlife. Methods of reseeding will influence the type of cover available for wildlife habitat. The revegetation test plots established by Colorado State University Department of Plant Science were designed to yield results identifying the factors required for optimum growth of the most favorable species. Methods have been chosen for drill seeding, transplanting, planting in relation to exposure, the season of seeding, application of fertilizers, and potential weed control. Climatic interpretations of the evapotranspiration with respect to slope aspect and gradient were required as well as a discussion of the variability of climate with time. Estimates of the costs of various reclamation activities were provided, including cost analysis curves for recontouring a typical area, topsoiling the final cut, topsoiling reclaimed areas in a typical year, cost per mile of diversion and drainage ditches, seeding costs, transplant costs, habitat improvement, and bonding regulations.

Along with James Walsh and J. Warren Thackston of the V.T.N. project team, the author forwarded recommendations supplementing those mentioned above. With regard to the stripping and stockpiling of topsoil, attention was given to the volumes of topsoil available, areas to be stripped, depths to be stripped, soil borrow areas, location of stockpiles, size and orientation of stockpiles, care and treatment of stockpiles, and disposal of debris. The discussion of the redressing of topsoils involved timing, machinery, thickness, and surface treatments. The handling of spoils was discussed next, with particular attention paid to the degree of compaction desired, and the treatment of the spoil-soil interface. In addition, methods of surface water diversion were discussed, including location and alignment of diversions, slope gradients, runoff capacity, erosion control, maintenance, and water treatment. The highlight of the reclamation plan for the Colowyo Mine thus becomes the description of the nature of the recontoured surface. A synthesis of recommendations pertaining to areas of critical concern from the aforementioned topics was used to present design criteria for slope angles, slope exposures, slope lengths, reduction of highwalls, and aesthetic character of the reclaimed surface. Concurrent with recommendations based on environmental and economic criteria, a synopsis of legal considerations was presented.

The fourth goal of the reclamation plan for the Colowyo Mine was to present the data and recommendations in a clear and concise manner which would address the traditional problem of conveying the information to the actual mine operators. The final publication was designed in the "STOP format", popularized by James A. Carte and Ronald A. Landers of the West Virginia Geological and Economic Survey. As summarized by Carte and Landers, the STOP format (an acronym for Sequential Thematic Organization of Publications):[14]

> is a report-writing and publication technique that presents a technical report in a series of essentially independent, two-page presentations called STOP units. The left page of each unit contains a minimum of text consisting of (1) section heads and (or) subheads at the top of the page, (2) a thematic heading similar to a newspeper headline, (3) a thesis sentence similar to a lead paragraph of a news story in a newspaper, and (4) the main body of text. The right page of each unit generally consists of graphical information that illustrates the text or that conveys the primary message.

Utilizing this format, the reader has the total text and graphical information on facing pages for the particular recommendation. For example, the STOP unit with the section head, "The Final Reclaimed Surface," would have a thematic heading: "Recontouring". This would be followed by a thesis sentence such as: "Slope Angles, Exposures, and Lengths plus Highwall Reduction Seen as Pertinent to a Stable Reclaimed Surface." The text then follows with the specific recommendations and the criteria used in their derivation.

Working closely with the graphics design personnel at V.T.N., the project team members for the Colowyo reclamation study followed the fourteen step procedure to produce the STOP format used by the West Virginia Geological Survey. The procedure maximizes the efficiency of researchers, graphics personnel, and editors by tracing the sequence below:[15]

> 1) Conduct research; 2) Define your reader; 3) Set objectives; 4) Develop topic outline; 5) Expand topic outline into sentence outline; 6) Formulate STOP units; 7) List key points of each STOP unit; 8) Prepare profiles; 9) Hold storyboard conference; 10) Revise and prepare final draft; 11) Type or compose final copy and prepare final graphics; 12) Review final copy with applicable graphics; 13) Make final corrections and changes; 14) Publish.

RECOMMENDATIONS FOR THE COLOWYO MINE RECLAMATION PLAN

As a member of the V.T.N. project team for the Colowyo reclamation plan, the author has forwarded recommendations derived from principles of geomorphology and the analysis of aesthetic resources. Although actually published in the STOP format, the full derivation of each recommendation is fully discussed below, involving the stripping and stockpiling of topsoil, the handling of spoil material, the nature of the final reclaimed surface, watershed boundaries, and the design of channels. The design criteria presented were derived for conditions at the Colowyo Mine and may not be applicable to other surface coal mines with differing geographic settings. Nevertheless, the justicication for each recommendation is presented in hope for promoting a sound methodology for use in deriving future reclamation plans elsewhere.

The Stripping and Stockpiling of Topsoil

The Colorado State Land Reclamation Board has promulgated a list of performance standards regarding reclamation. Topsoil removal prior to any mining activity is required, as well as a description of the procedure and equipment to be used.[16] The stripping of topsoil will be facilitated by the use of a paddlewheel scrapper, based on their effective removal of thin layers of topsoil at the Energy Fuels Mine. Scrappers have excellent mobility, but have been shown to be most economically operated when used in a 1.6 kilometer (1 mile) radius. Such a small operating radius precludes the need for supporting disposal equipment, although pushers will be needed to assist in the leading.[17] Well constructed and maintained roads are required in order to minimize the considerable tire costs, and they should only be used on soft and easily broken material, handling rocks up to 61 centimeters (24 inches) in diameter. The paddlewheel scrapper will allow a segregation of topsoil, described as clayey-loam to sandy clay loam, from subsoils which range in texture from clay to sandy clay loam containing gravel and rock fragments. This will prevent the dilution of organic matter in the A horizon, currently averaging five percent.[18]

With regard to the stockpiling of topsoil, the Land Reclamation Board requires areas established for this purpose to be located outside of the mining zone and with no rehandling of topsoil until redressed.[19] Because of the limitation imposed by the most efficient operating radius of the scrappers, the stockpiling of topsoil should be undertaken in an area within a 1.6 kilometer (one mile) radius of the stripping operation. Moreover, the topsoil should be placed in long, mounded terraces in an area protected from erosion due to wind, runoff, and raindrop splash. Thus, the topsoil should not be placed on ridgetops, nor in adjacent canyon headlands where the topsoil will be subject to wind ablation created by eddies topping the ridge.

For the first four years of the project, there will be a disparity between the area disturbed and the area reclaimed each year. The topsoil handled during this four year span must be stabilized, as will the topsoil stockpiled thereafter which will require stabilization for only one year as per the State's quidelines (Table 1). For the initial topsoil accumulated over the first four years of the project (to be replaced in part during the fifth year), erosion protection measures should be based on the maximum precipitation intensity and surface runoff expected for a four-year storm. No such data

Table 1. Colowyo Mine Production Schedule

YEAR OF MINING	NEW SURFACE AREA DISTURBED PER YEAR (Hectares)	DISTURBED SURFACE AREA RECLAIMED PER YEAR (Hectares)	OVERBURDEN REMOVED PER YEAR (Cu. Meters)
1	286.5	0	1,456,000
2	51.9	0	2,184,000
3	56.8	0	3,068,000
4	106.2	56.8	7,800,000
5	106.2	106.2	7,800,000
6	106.2	106.2	7,956,000
7	106.2	106.2	8,112,000
8	106.2	106.2	8,268,000
9	106.2	106.2	8,424,000
10-15	106.2	106.2	8,580,000
16-19	106.2	106.2	8,892,000
20-25	106.2	106.2	9,360,000
26-30	106.2	106.2	10,140,000
31	0	444.6	0
Total	3,015.9	3,015.9	248,976,000

Source: V.T.N. Engineers-Architects-Planners, *op.cit.*, footnote 1, p. 24 (later revised by W.R. Grace *and Co.*)

exist for the Colowyo Mine area, although an estimate of a 100-year, one hour precipitation of 3.8 centimeters (1.5 inches) has been promoted by the Bureau of Reclamation. A surface runoff of 28.3 cubic meters per second (100 cubic feet per second for Streeter Draw has been similarly predicted.[20]

Wind ablation and erosion from sheet flow can be mitigated by seeding the topsoil with fast growing legumes and wheatgrasses supplemented by the use of jute metting, a heavily woven material of yarn. Jute netting was judged in tests on steep slopes to provide the best protection of any mulch treatment against raindrop splash while adhering to the soil surface (Table 2).[21] Jute netting, as a mulching technique, is very efficient in conserving moisture and providing protection against intense solar radiation.[22] A hydro-wood fiber mulch will prove to be long-lasting and when highlighted with green dye is aesthetically pleasing. It will aid in holding the seed in place if applied at rates of 1000 to 3000 pounds per acre. Wood fibers should be used with caution as they have been shown to cause an upset in the nitrogen content of surface soils. Studies have shown little difference in effective erosion control between the use of wood fiber mulches and the use of washed dairy waste, ground paper, rice hulls, and ground barley straw. However, these latter methods either do not adhere to

Table 2. Mulch Treatments and Relative Effectiveness for Erosion Control on a Thirty-three Percent Slope

TREATMENT: Application	RELATIVE EROSION (Number of times erosion from jute net mulch)
JUTE NETTING: Heavy woven jute matting with a 1.6 x 1.1 yarn count	1.0
WOOD EXCELSIOR MAT: High grade wood excelsior covered on both sides with a strong, large mesh, kraft netting	1.1
FIBERGLASS ANCHORED WITH ASPHALT EMULSION: Fiberglass anchored with 1:5 asphalt emulsion	1.4
WOODCHIPS ANCHORED WITH ASPHALT EMULSION: Pine woodchips from a portable chipper and anchored with 1:5 asphalt emulsion	2.3
PRAIRIE HAY ANCHORED WITH ASPHALT EMULSION: Prairie hay anchored with 1:5 asphalt emulsion	2.5
ASPHALT EMULSION: An emulsifiable asphalt diluted 1:1 with water and sprinkled on plot	22.5
CORNCOBS ANCHORED WITH ASPHALT EMULSION: Ground corncobs slightly larger than ¼ inch in diameter and anchored with 1:5 asphalt emulsion	4.5
FIBERGLASS: Continuous filaments of fiberglass applied with compressed air	7.9
KRAFT PAPER NETTING: Tightly twisted kraft netting with a 7 x 4 yarn count	

Source: Extracted from A.E. Dudeck, *op. cit.*, footnote 6.

the soil surface as well as wood fiber, are aesthetically unpleasing, or are difficult to apply effectively.[23] In the final analysis, jute netting will provide the optimum erosion control and conservation of soil moisture with any hydro-wood mulches rated secondary.

The Handling of Spoil Material

The material nature of overburden can be predicted through knowledge of the lithology of strata to be disturbed, operating machinery, mining methods, time, and expected weathering processes. The overburden will be generated from the sandstones, sandy shales, and carbonaceous shales composing the Williams Fork Formation. After the first three years of operations, 12.9 million cubic yards of overburden will have accumulated. Thereafter, the amount of overburden stored in any one year will range from 7.8 to 10.1 million cubic meters (15 to 19.5 million cubic yards). This material will have been blasted and removed by a walking dragline and deposited by a rock shovel into trucks for transport to stockpiling areas. Material removed in the first year of mining operations will be exposed in spoil piles for three years; material removed in the second year will be exposed for two years, and material removed in subsequent years will be exposed for only one year.

The exposed overburden will be subject to the following relative degrees of weathering, as defined by L.C. Peltier: strong chemical weathering, strong wind action, strong to maximal pluvial erosion (raindrop splash, sheet erosion, and channel erosion), and weak to minimal mass wasting.[24] Field investigations have shown this prediction to be fairly accurate, modified only by lithologic variables. Chemical weathering, for instance, is evident throughout the property, but is most prevalent on south and west aspects where coal is quickly oxidized, solution cavities are common, and iron-staining is found. Relict slumps are rarely seen due to the dense vegetative cover, such that rockfalls from resistant, outcrops of jointed sandstone constitute the only visible form of mass wasting. The soil surface shows signs of exposure to wet-dry cycles in the form of physical decay and cracking, accentuated by the high clay content of soils. Severe cleaving and cracking accounts for total breakdown of shales found at the Colowyo Mine site. Only partial breakdown of sandstones for cracking accurs. Siltstones and mudstones weather even less rapidly but are subject to fractures and iron-staining.

When the described strata are exposed to above mining methods and weathering processes over the time span expected, an overburden will be produced which will be high in clay content, has a higher porosity, contains less organic matter, and is poorly compacted since the degree of cementation has been altered. The physical disintegration of spoil material can be expected to be rapid for the first three to five years after unearthing, confirmed by experience at the Edna and Energy Mines. Greater runoff and evaporation is anticipated on the new fine-textured soils.

The Colorado State Land Reclamation Board requires placement of spoil piles in an area and manner which will minimize off-site damage.[25] Experience with the steep-sloped spoil piles at the Edna Mine has shown that "topping-off" the spoils will not prevent slips at the shoulders of the piles. Retention of spoils in place is not as critical as it is with stored topsoil, although sediment yield must be checked. Retention dams should be established downgradient from the spoil piles to catch sediment emanating from slips, sheetflow, and mudflows at the toe of spoil piles due to water seepage along the plane between the spoil piles and the supporting ground surface. Spoil piles should also be aligned parallel to the strike of the slope.

The degree of compaction desired on the overburden when recontouring depends on the swell factor encountered as well as the clay content in the spoils. With a high percentage of clays expected in the spoils, some natural settling can be expected along with cementation during wet-dry cycles.[26] At the Edna Mine, which has a similar lithology of the overburden, most settling occurred in the first year after recontouring the spoil piles. Natural compaction attributable to these factors along with the compaction attainable with mine machinery traversing the area may not create the most desirable water balance.[27] Consequently, Hal Maulde of the United States Geologic Survey has suggested the use of a "sheeps-foot" compactor on the spoils prior to the redressing of topsoil. The U.S.G.S. has also advised that the upper 6.1 meters (20 feet) be compacted to seventy-five percent of optimum with the upper 0.6 meters (2 feet) compacted to eighty-five percent of optimum.[28]

The net change in elevation of the mined landscape will also influence the degree of compaction desired. Two opposing factors enter into the change: the total volume of coal removed, and the swelling of the replaced overburden. The former subtracted from the latter will give the net change in volume of material which can then be converted to a change in elevation by dividing this volume by the total surface area mined.

A variety of swell factors for replaced overburden material have been derived for similar calculations at other mine sites, but a value between twenty and twenty-five percent has been deemed appropriate for the Colowyo

Mine. This is based on the experience at the Edna and Energy Mines which have encountered similar lithologies. Table 1 reports a total amount of overburden to be removed over the lifetime of the project of 248,980,000 cubic meters (478,800,000 cubic yards). When replaced, this overburden will swell in volume because of the loss of natural compaction achieved over geologic time. The gain in volume will vary with the swell factor utilized:

$$248,980,000 \text{ m}^3 \times 20\% = 49,795,200 \text{ m}^3$$
$$248,980,000 \text{ m}^3 \times 25\% = 62,245,000 \text{ m}^3$$

The loss in volume due the extraction of coal must be subtracted from these values in order to obtain the net change. The Draft Environmental Impact Statement for the Proposed Colowyo Mine reports a total of 18.11 meters (19.8 yards) for the average cumulative thickness of all coal seams to be mined. To obtain the volume of coal to be removed over the lifetime of the project, one need only multiply this value by the total area to be disturbed, which is 3,359,781.9 square meters (4,018,397 square yards):

$$3,359,781.9 \text{ m}^3 \times 18.11 \text{ m} = 60,845,652 \text{ m}^3$$

The net change in volume will thus depend on the swell factor. With a twenty percent swell factor, the net change will be negative:

$$49{,}795{,}200\ m^3 - 60{,}845{,}652\ m^3 = -11{,}050{,}452\ m^3.$$

With a twenty-five percent swell factor, the net change will be positive:

$$62{,}245{,}000\ m^3 - 60{,}845{,}652\ m^3 = +1{,}399{,}348\ m^3.$$

To obtain the net change in elevation, one needs only to divide the volumes by the area to be affected:
with 20% swell,

$$-11{,}050{,}452\ m^3/3{,}359{,}781.9\ m^2 = -3.39\ m\ (-10.79\ ft.);$$

with 25% swell,

$$1{,}399{,}348\ m^3/3{,}359{,}781.9\ m^2 = +0.41\ m\ (1.37\ ft.).$$

Thus, if the actual swell factor for the overburden turns out to be twenty percent, there will be an average loss of 3.39 meters (10.79 feet) over the area to be disturbed as opposed to an increase in average elevation of 0.41 meters (1.37 feet) with a twenty-five percent swell factor.

The Final Reclaimed Surface

The angle, exposure, and length of recontoured slopes are critical factors to be considered when attempting to reduce sediment yield, retain soil moisture, and prevent mass wasting. These hazards may also be mitigated through various treatments of the final reclaimed surface, including scarrification and terracing. In addition, the final highwall left by the mining operation must be reduced in order to avoid mass wasting, water pollution, safety hazards, and visual detractors from the characteristic aesthetic setting. The Colorado State Land Reclamation Board offers no specific requirements regarding these factors, but they do have the authority to approve the reclamation measures submitted in the permit.

To determine the maximum slope angles and lengths for various exposures, four criteria were considered. First, it has been found that a slope of fifty percent is the maximum angle possible for any sustained vegetation growth, although slopes less than thirty-three percent are more desirable for maximum vegetation stability.[29] Second, maximum slope angles must allow the use of scrappers for redressing of topsoil. Since the proposed land use after reclamation precludes any agriculture, no farm machinery will be needed on the site, a factor which might otherwise place a limit on maximum slopes of near thirty-three percent. Scrappers, however, have been known to operate on much steeper slopes. Third, soil moisture must be conserved by measures dependent on exposure as well as angle. Yet, the velocity of overland flow has been shown to increase with the square root of the slope, an increase which restricts infiltration. This factor is emphasized by the fine-textured soils which will cause a high surface runoff and evaporation, as mentioned previously. Fourth, the length of slopes has a direct influence on the amount of sediment yield.

A slope class map was prepared to illustrate the distribution of various key slopes on the Colowyo Mine property (Figure 8). Ten percent by area of the site contains level to gently-rolling slopes in slope class 1 (0 to 6 percent). Thirty-three percent of the area falls in slope class 2 (7 to 13 percent). Thirty-five percent of the mine property lies in slope class 3 (14 to 25 percent); 18.5 percent of the site contains steep slopes in slope class 4 (26-50 percent); and 3.5 percent of the mine property has excessively steep angles in slope class 6 (over 50 percent). The existing gentle northerly-sloping topography precludes extensive south-facing slopes except on several mesa flanks along Streeter Draw and the Good Springs Creek sub-basins. It is noteworthy to mention that no linear relationship was found between slope class and drainage density with the latter showing a maximum for slopes between seven and thirteen percent and a secondary peak at twenty-six to fifty percent. It surface runoff is increased on the reclaimed surface as compared to the existing

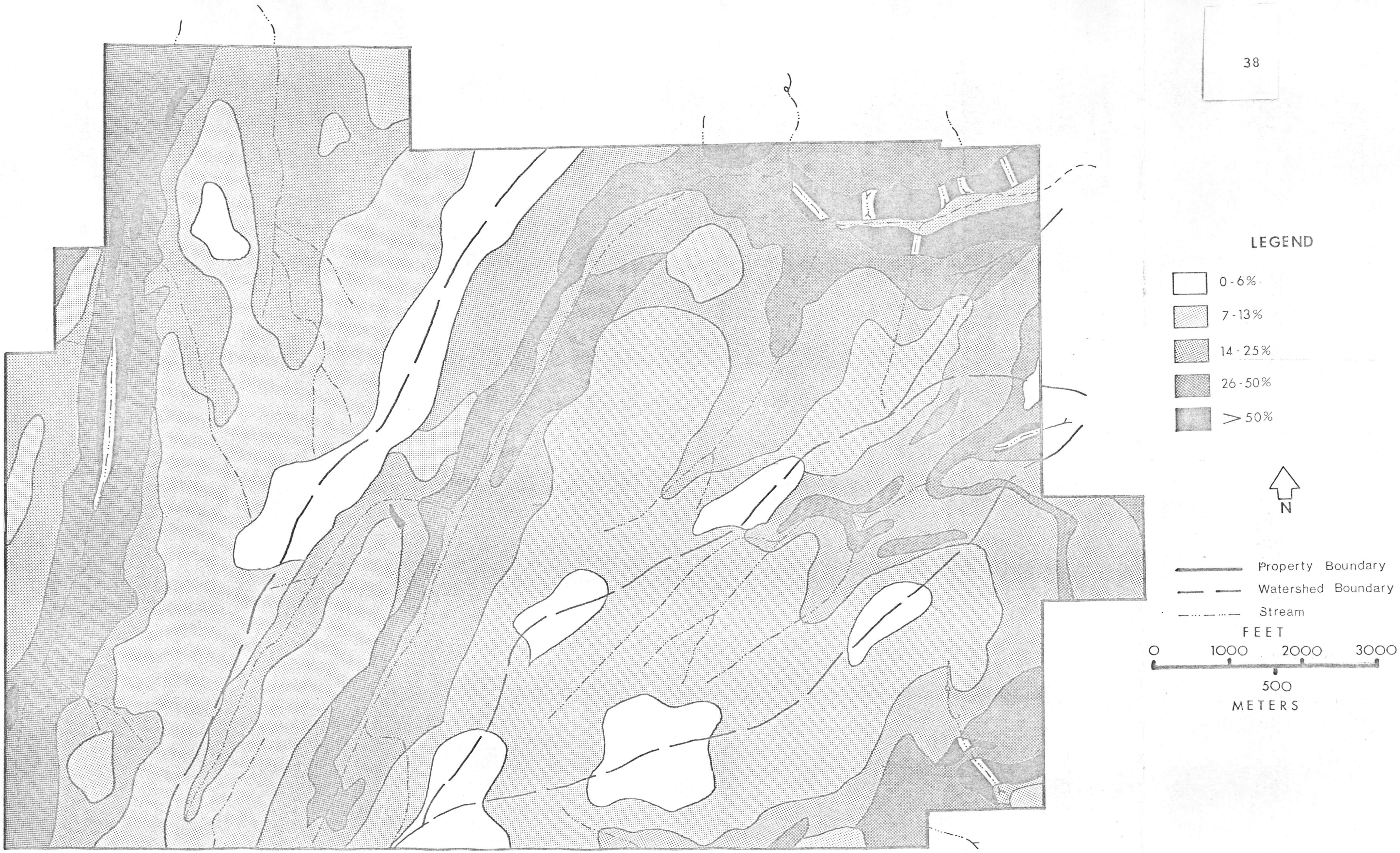

Figure 8. Slope class map of the Colowyo Mine. Source: Prepared by author.

surface, then it may be necessary to increase the drainage density. A preferred alternative is to create an undulating slope with numerous small depressions to retard overland flow as was seen to occur at the Edna Mine.

The steeper slopes existing at the Colowyo Mine must not be reproduced, especially on south and west aspects, in order to insure better moisture retention. High soil temperatures tend to result in droughty soils on these aspects, such that slope angles should be reduced to a maximum of thirteen percent (slope classes 1 and 2), as recommended by the mining engineer at the Edna Mine. Slopes on north and east aspects, which includes most of the existing mine property, support an improved mositure retention by virtue of the lower solar insolation. Nevertheless, slope angles on these aspects will have to be reduced to less than twenty-five percent, limited by the operating efficiency of scrappers, the optimum angle for revegetation, and slope stability. The latter factor achieves its importance when one realizes the effect of increasing the shear stress of a mass of soil on a slope from saturated conditions likely to occur on north and east aspects.

Slope angles in a lower slope class allow extended slope lengths. However, longer slope lengths increase the potential for rill erosion which may culminate in gullying. Thus, longer slopes on north and east aspects should be scarrified, as should all south and west exposures, in order to impeed surface runoff and increase infiltration. Scarrification, or contour furrowing, provides a roughenned soil surface from spoil spilling at the end of the angled blade of a bulldozer. As outlined by the Environmental Protection Agency, "the furrows are generally on the contour and range from 0.6 to 0.9 meters (2 to 3 feet) in height and are 0.9 to 1.2 meters (3 to 4 feet) between peaks."[30] Contour furrowing should be done in the season with the least intense rainfall to avoid compaction of the spoils by raindrop impact. The roughenned spoils also provide a stronghold for the topsoil when replaced. Otherwise, compaction might result in a slip plane between the replaced spoils and redressed topsoil.

Exposed highwalls left by the final mining cut will pose several hinderences to the proposed land use if not altered by reclamation. The highwall will comprise a safety factor to recreational users and livestock in the area and can be a visual detractor from the topographic character of the reclaimed landscape. The steep slopes, bedding planes for groundwater solution, plus any fracturing of exposed strata contribute to a potential for mass wasting. Furthermore, salts and other minerals entrained in the groundwater may ensue in a water contamination problem.

There are several types of backfilling methods used to reduce or eliminate the final highwall. Of those methods reviewed by the Environmental Protection Agency in Environmental Protection in Surface Mining of Coal, the contour backfill has been deemed most appropriate for the desired land use following mining at Colowyo.[31] A contour backfill requires enough material to cover the entire highwall by grading the spoils toward the highwall in order to approximate the original contour (Figure 9). At the Colowyo Mine, the angle of the backfilled ground slope may be high enough to require contour furrowing or use of jute netting to inhibit large releases of sediment.

Watershed Boundaries and Channel Design

The Colowyo Mine property is drained by Taylor Creek, Streeter Draw, and by three sub-basins draining directly into Good Springs Creek (Figure 7). The drainage patterns of the principle stream courses are subparallel and flow perpendicular to the regional strike of geologic units. This pattern is partially controlled by a system of "subparallel joints in rock units which have created zones of weakness in the mesa capping sandstone beds, thus allowing more rapid erosion by streams."[32] Although this structural control on drainage patterns will be eliminated by the surface mining activity

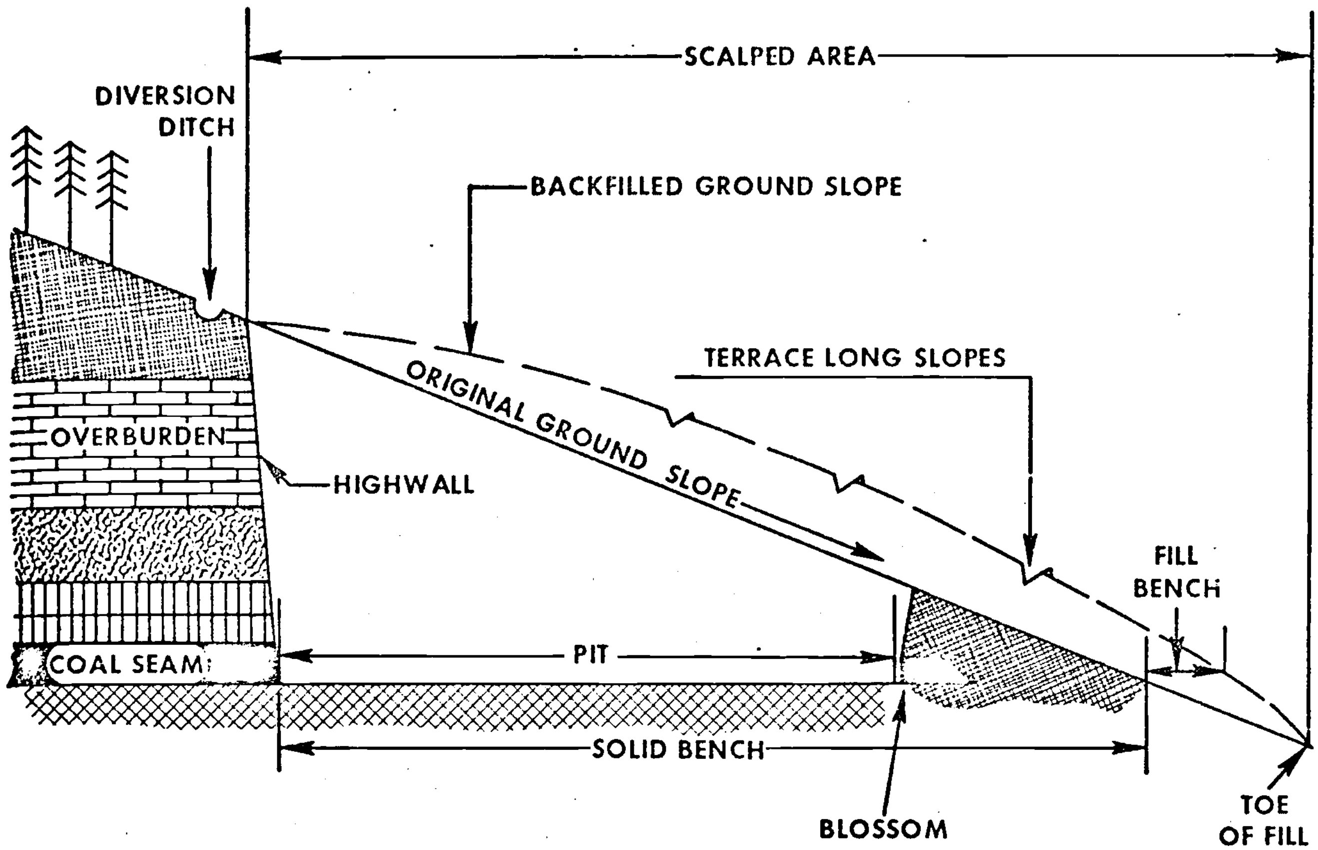

Figure 9. Diagram of typical contour backfill. Source: Elmore C. Grim and Ronald D. Hill, op. cit., footnote 3, p. 157.

in all basins except Taylor Creek, it is nevertheless critical to restore the elongate shape to the basins. Streeter Draw and the sub-basins to Good Springs Creek (labelled GS-1, GS-2, GS-3) are elongated to the degree that low bifurcation ratios prevail. This is characteristic of basins with small water yields and has the noticeable effect of tempering peak flows when one compares theoretical hydrographs (Figure 10). Restoration of the parallel drainage pattern with elongated basin shapes will prevent early, high peak flows which provide a maximum amount of kinetic energy available for channel erosion and undercutting of banks. Retention of existing watershed boundaries will also preserve the relative disposition of precipitation entering the mine property. This will prevent excessive stormflow concentrated in any one basin even though the disposition of precipitation into the various components of the hydrologic cycle will be altered.

A map was prepared which depicts the contours of the final reclaimed surface (Figure 11). This map must accompany the permit application submitted by W.R. Grace and Company before approval of the mining plan as required by the Colorado State Land Reclamation Board.[33] Four primary criteria were used to construct the new contour lines for land disturbed by the mining operation. First, it was necessary to meet the existing contours outside of the Colowyo Mine property with no

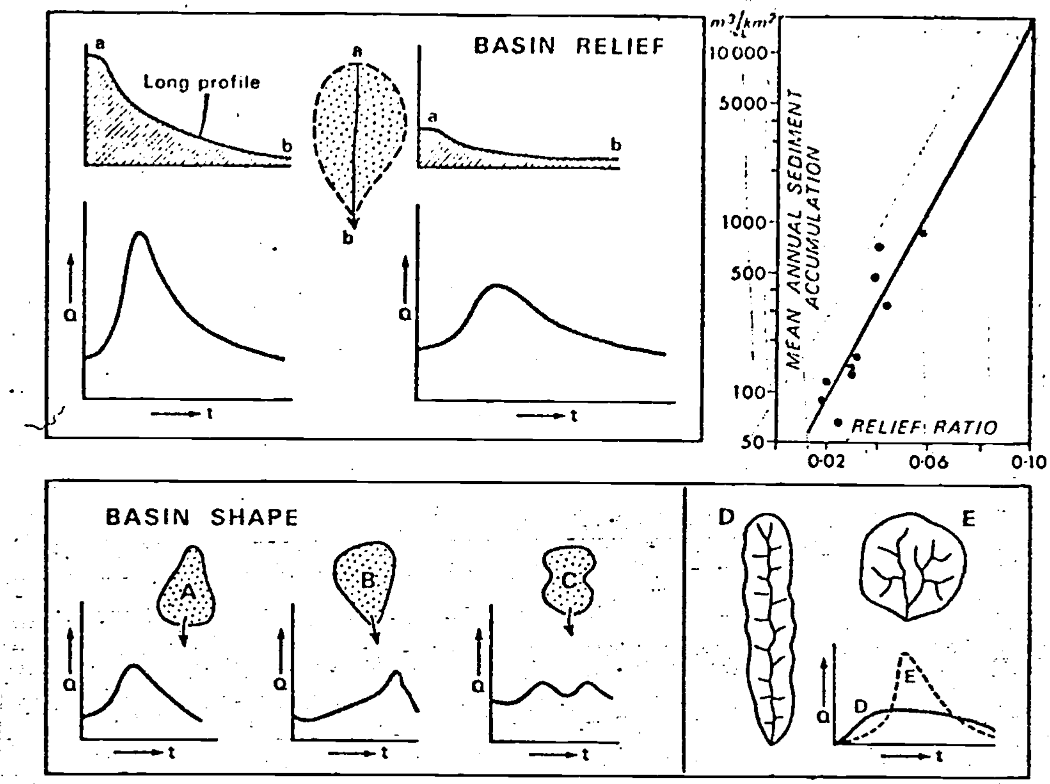

Figure 10. Diagrams illustrating the relationship between drainage basin relief, shape, and the shape of the hydrograph. The existing shapes of Streeter Draw Basin and GS-1 and GS-2 will be retained in order to dampen peak flows as typified by basin D above. Source: K.J. Gregory and D.E. Walling, Drainage Basin Form and Process (New York: John Wiley & Sons, 1973), p. 269.

Figure 11. Map of the proposed final reclaimed surface for the Colowyo Mine. The proposed new channels are shown with dashed lines separated by three dots. The recontoured surface is shown by heavy continuous lines with 100 feet intervals. The existing topography is reproduced in light tone lines. Source: Prepared by author.

major break in slope. Otherwise, an escarpment would be left which might cause slope stability problems with legal implications to adjacent landholders. Second, watershed boundaries were maintained for reasons stated earlier, a step which preserves the direction of contour crenulations on drainage divides. Third, slopes were reduced to a maximum of thirteen percent on south and west aspects, and a maximum of twenty-five percent on north and east aspects. This was accomplished by a greater separation of contour lines for those areas with slopes exceeding these limits. Fourth, it was desirable to create a redistribution of mass in the watershed which would create an overall mature basin gradient, as opposed to a young or old age basin.

Hypsometric analysis, a technique developed by Arthur N. Strahler, was undertaken in order to describe the present distribution of mass for each of the four basins affected by mining operations.[34] The technique was then used to construct a recontoured surface which would approximate the characteristics of a mature (or steady-state) basin as described by William Morris Davis and J.T. Hack. Such a stage of basin development would avoid the conditions of high velocity streamflow, active channel downcutting, and soil creep noted for youthful systems. Because of the constraints imposed by meeting contour lines on property adjacent to the Coloyo Mine, considerable relief will be retained for each basin, negating the possibility of established an old age basin. Hypsometric analysis involves constructing a curve with the abscissa of the graph scaled from zero to 1.0, an indication of the ratio of area between successive contours (a) to the total drainage basin area (A). The ordinate is also scaled from zero to 1.0, describing the ratio of the height of the contour above base level (h) to the total height of the basin (H; Figure 12).

The resulting curve reveals several facts about the drainage basin. First, experience has shown that basins described by a large area under the curve (the hysometric integral) typically have low relief, gentle slopes, gentle stream gradients, and a low drainage density. The converse applies to basins with low integrals which typically have strong relief, steep slopes, steep stream gradients, and a high drainage density. Along these lines, Strahler has prepared a graph of three hypsometric curves describing basins with characteristics corresponding to the Davisian cycle of erosion (Figure 10).

The goal for recontouring the final reclaimed surface was to create basins with mature gradients as described by the hypsometric curve. If one compares the hypsometric curves for the existing and reclaimed landscape in each basin, it is found that the shift from the existing curve is toward more youthful conditions in the upper half of the basin and toward more old-age

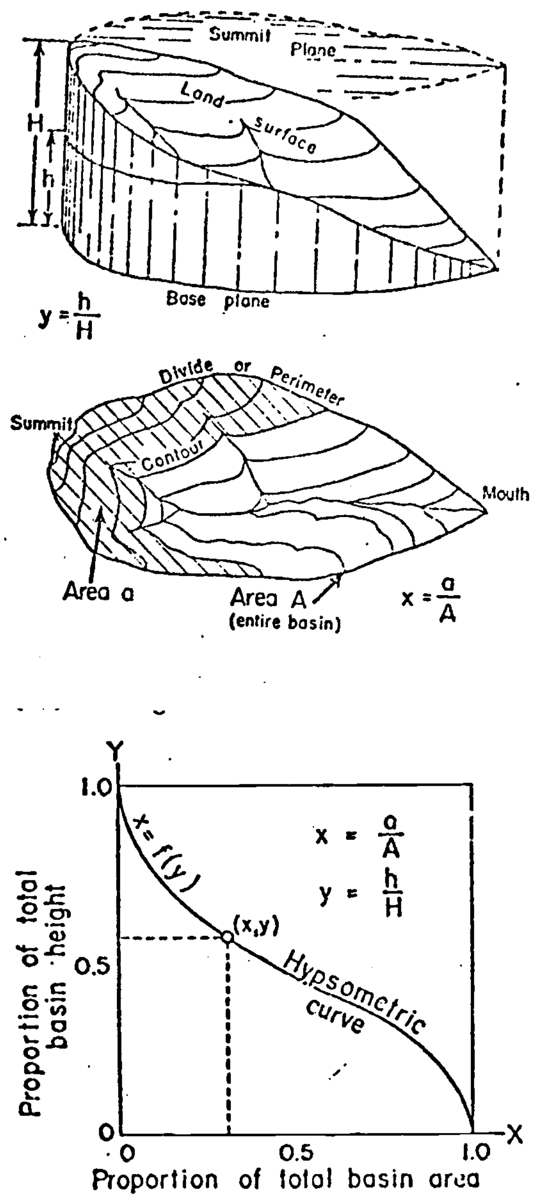

Figure 12. Diagrams illustrating the derivation of the hypsometric curve. Source: Arthur N. Strahler, op. cit., footnote 34, pp. 1119-1120.

conditions in the lower elevations (Figures 13 to 17). This is largely necessitated by producing the recommended slope angles. The existing topography for all four basins contained the steepest slopes near the lower elevations, contrary to equilibrium conditions required for a channel to achieve grade.

Channels on the reclaimed landscape were constructed for aesthetic reasons in order to re-establish the characteristic topography as well as to facilitate a reduction of slopes in critical areas. For instance, in the southeast portion of the Colowyo Mine property, two first order channels were added to cause the contour crenulations to move upgradient and hence reduce potentially oversteepened reclaimed slopes along those channels draining GS-2. The intermittant stream in Streeter Draw will remain unaltered and the two main tributaries will be extended over their existing length. In GS-1, the existing bifurcating, sub-parallel system will be eliminated in favor of a single main channel, considered sufficient for the maximum anticipated stormflow.[35]

Although the creation of a basin supporting energy conditions characterized by a mature system is intended to reduce downcutting, it will not be avoided unless rapid revegetation of the waterway quickly follows the recontouring. Otherwise, downcutting of the channel along with bank erosion will force the construction

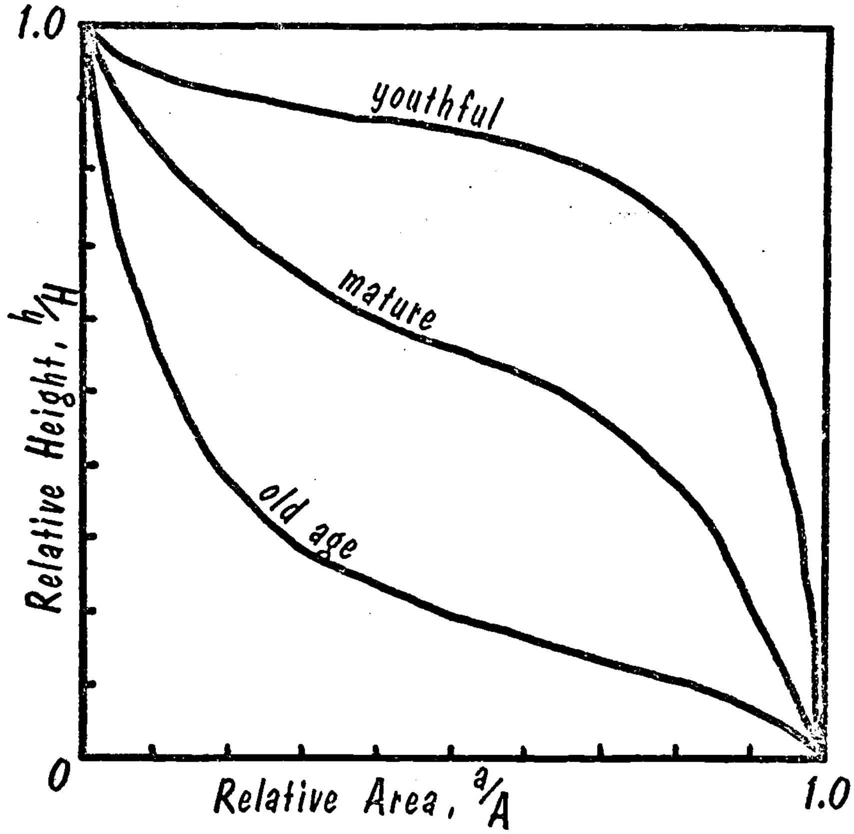

Figure 13. Theoretical hypsometric curves for youthful, mature, and old age basins. Source: Adopted from Arthur N. Strahler, op. cit., footnote 34, p. 1124.

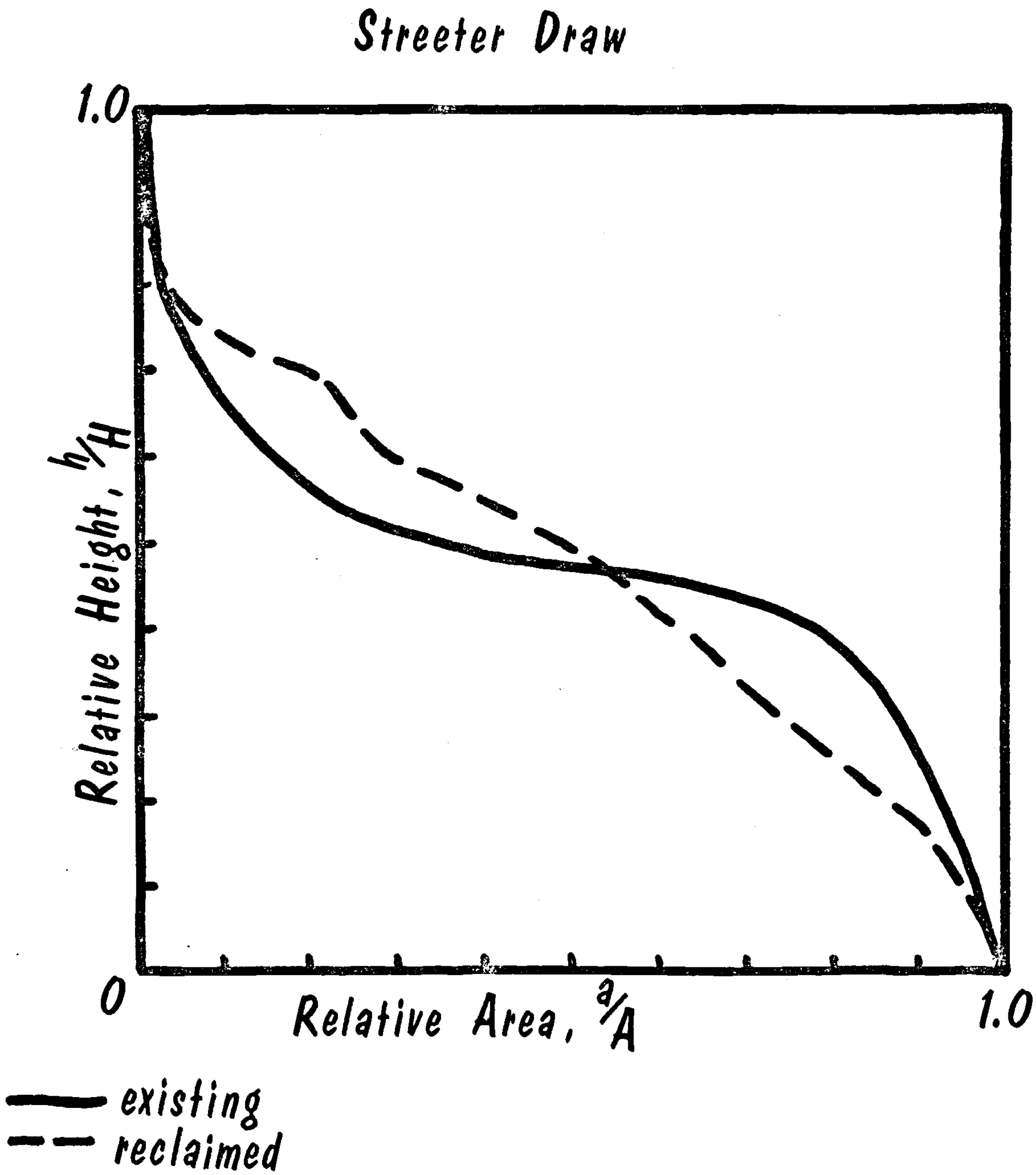

Figure 14. Hypsometric curves for existing and reclaimed topography in Streeter Draw Basin. Note trend toward creating more youthful conditions in the upper portion of the basin and more old age conditions in the lower portion of the basin. Source: Prepared by author.

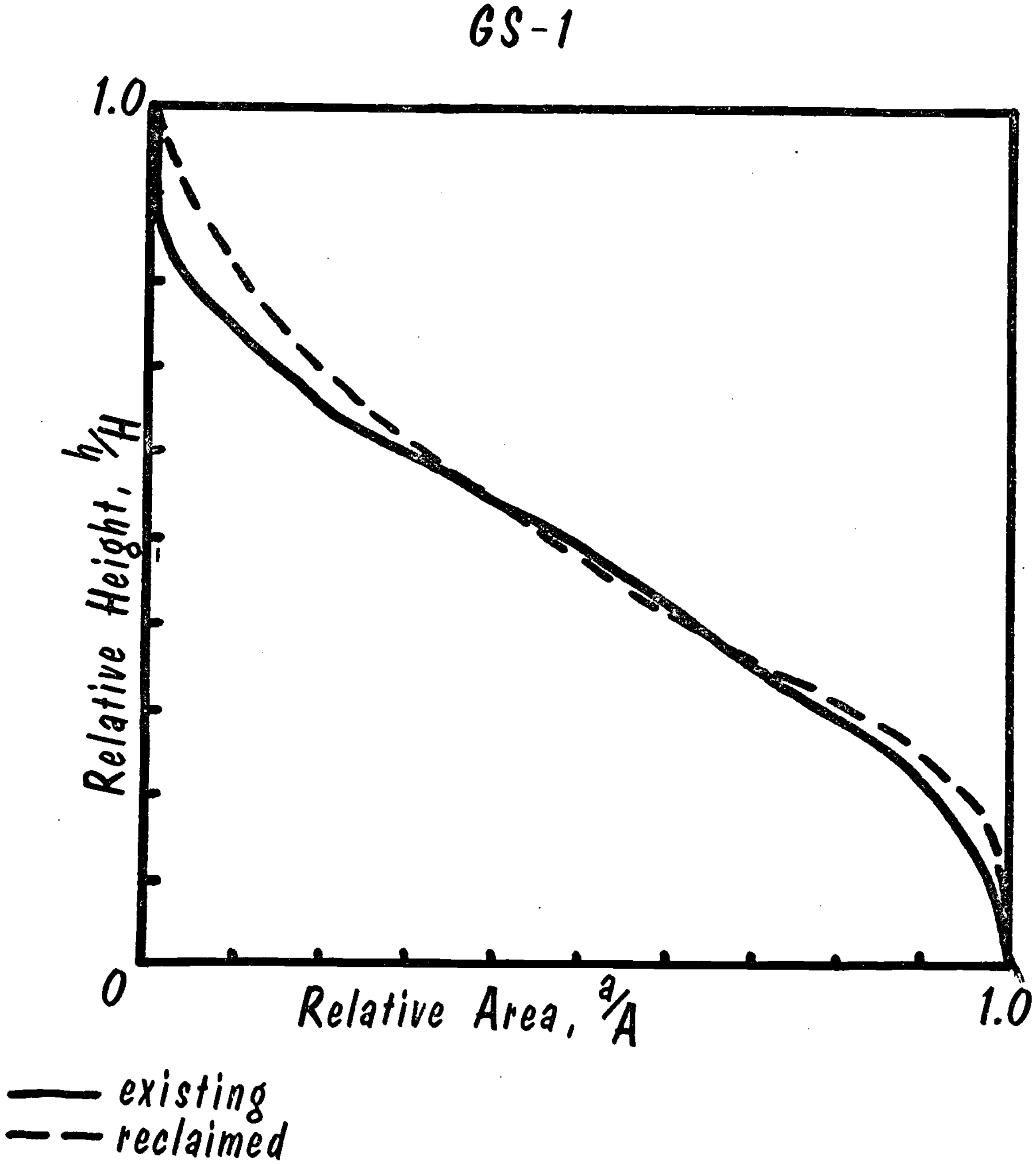

Figure 15. Hypsometric curves for the existing and reclaimed topography in GS-1. Source: Prepared by author.

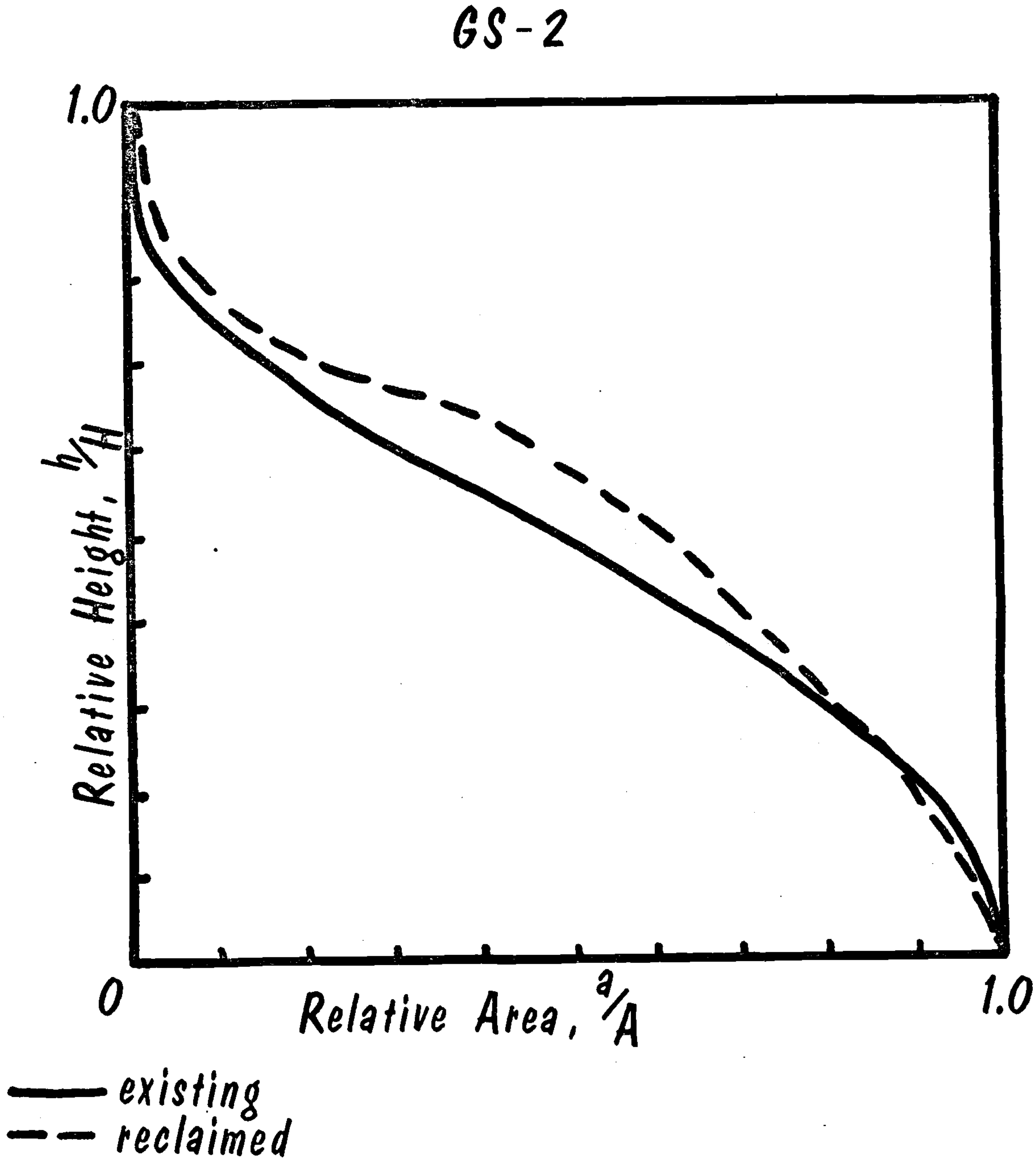

Figure 16. Hypsometric curves for the existing and reclaimed topography in GS-2. Source: Prepared by author.

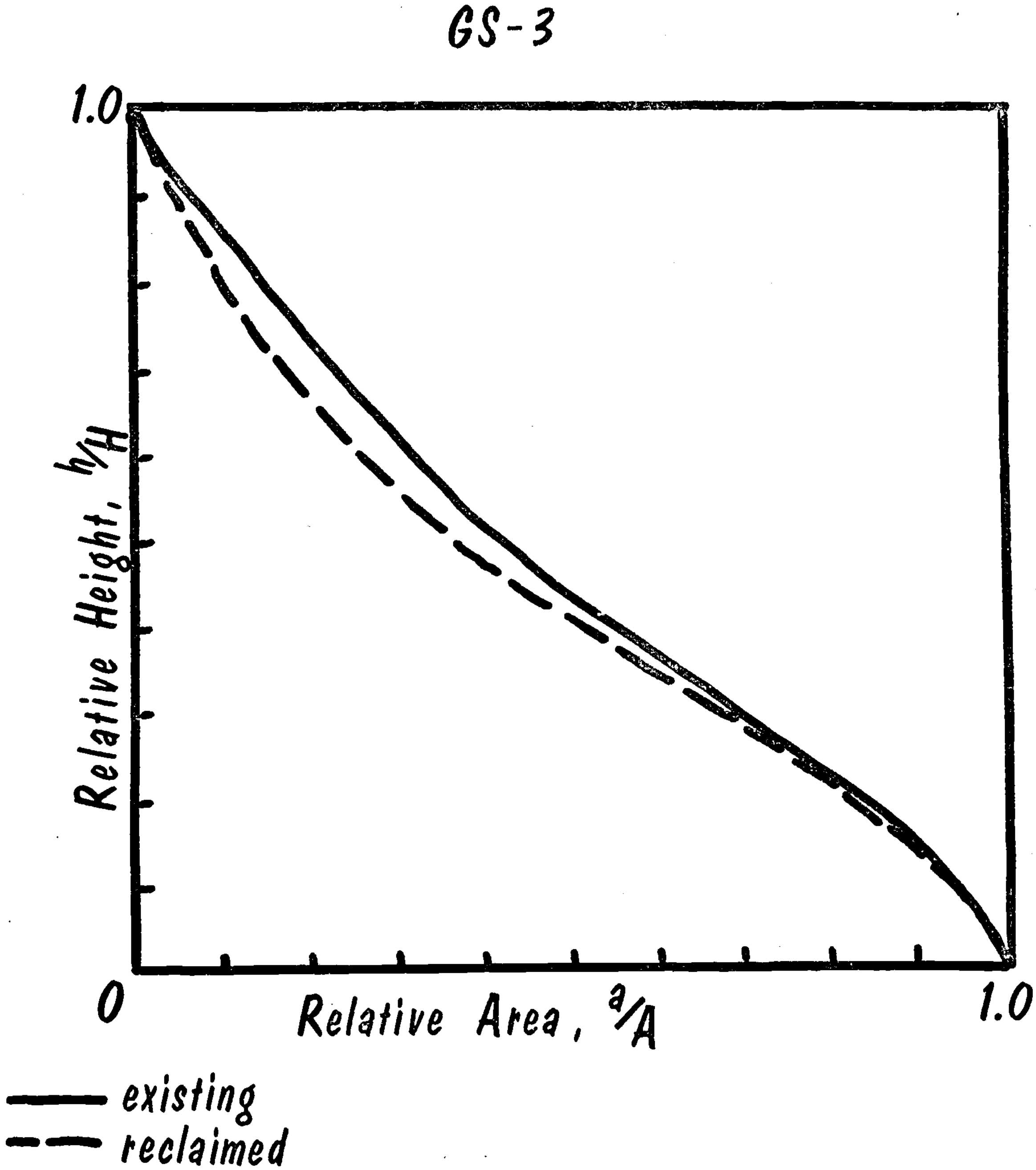

Figure 17. Hypsometric curves for the existing and reclaimed topography in GS-3. Source: Prepared by author.

of grade control structures to promote aggradation and retard the velocity of channel runoff. The use of such check dams is restricted to low flow channels not subject to severe flooding, conditions present in the existing drainage. Grade control structures may be supplemented by providing direct bank protection through the use of revetments such as rip-rap, fabriform, mats, and gabions. These materials can adjust to a change in the channel foundation, although compaction prior to application will preclude settlement.[36] Stone or rock revetments are undesirable from an aesthetic standpoint but could be used along channel reaches which have an exceptionally high water table or on excessively droughty soils.

The channel bed and banks should be planted with species comprised of dense roots to adequately bind the soil. The species chosen should be able to withstand the accumulation of colluvium in the channel from slope wash. Grasses, legumes, other low growth forms, and dead litter will act to filter sediment, dissipate erosive energy from raindrops and channel flow, and enhance infiltration.[37] The seedbed should be firm, but not too well compacted and should be supplemented with a crop residue or mulch to protect the waterway and grass seedlings during early growth. The U.S. Department of Agriculture has published a list of grasses and legumes commonly used in waterways of the Great Plains, including tall fescue, smooth bromegrass, Bermudagrass, intermediate wheatgrass, western wheatgrass, big bluestem, Indiangrass, created wheatgrass, Siberian wheatgrass, and King Ranch Bluestem. Good quality seed should be planted at the best date for each particular species using planting techniques and equipment best suited for attaining the maximum root density. Livestock and equipment should be made of the channel after each intense rainstorm. Bare or damaged spots should be reseeded or repaired with sod or mulch.[38] Properly vegetated channels with a uniform cover will lend a flowing dimension to the constricted views in the drainages. Prevention of erosion by vegetating waterways will eliminate extensive gullying as a detracting factor to the visual landscape.

SUMMARY

The reclamation plan for the Colowyo Mine in Moffat County, Colorado, which was prepared for W.R. Grace and Company by V.T.N. Engineers-Architects-Planners was based on four goals. First, the reclamation plan must be incorporated into the mining plan such that environmental constraints to recontouring are reconciled with the practical operating limits of mining equipment. Second, an interdisciplinary approach was utilized in order to fully appreciate the complexities in formulating a physically stable reclaimed surface. Third, it was necessary to identify and mitigate the possible hazards inherent in reclaiming a surface coal mine. Fourth, the data and recommendations were presented in a concise format which would minimize the traditional problem of conveying the information to the actual mine operators.

Two active surface coal mines in northwest Colorado were toured in order to become familiar with current reclamation techniques and problems. Reclamation efforts at the Edna Mine revealed a minimum commitment by Pittsburgh and Midway Coal Company to successfully restoring a productive landscape. No topsoil has been stockpiled, sediment and soluble salts emanating from unfilled open cuts are released to off-site streams, compaction of regarded spoils has been poor, and revegetation has been sparse with undesirable species. In contrast, reclamation at the Energy Fuels Mines offered numerous examples of techniques which were adapted to conditions at the Colowyo Mine. Topsoil is stripped in thin layers and segregated by horizons with the use of paddlewheel scrappers. When redressed on the graded spoils, the soil is shaped, disced, and harrowed. More effective controls on the release of sediment and soluble salts were exerted by the Energy Fuels Corporation, and revegetation was aided by drill seeding as opposed to aerial seeding.

The positive and negative aspects of the Edna and Energy Fuels reclamation efforts were incorporated with a literature search, interviews, and field work in order to produce sound recommendations for the Colowyo Mine reclamation plan. The design criteria for the stripping and stockpiling of topsoil, the handling of spoil material, the nature of the final reclaimed surface, and the design of watershed boundaries and channels comprised the author's contribution to the plan and are summarized below in synopsis form:

1. Remove topsoil with a paddlewheel scrapper and stockpile with a 1.6 kilometer (1 mile) radius of the mining operation. Place the topsoil in long, mounded terraces stabilized with jute netting and seed with fast growing legumes and wheatgrass;
2. use retention dams downgradient from the spoil piles which have been aligned parallel to the strike of the slope. Compact the upper 6.1 meters (20 feet) to seventy-five percent of optimum with the upper 0.6 meters (2 feet) compacted to eighty-five percent of optimum. Replaced overburden should be scarrified (contour furrowed) prior to redressing of topsoil;
3. reduce slopes on south and west aspects to a maximum of thirteen percent and to a maximum

of twenty-five percent on north and east aspects. All south and west facing slopes should be scarrified as well as the longer slopes on north and east exposures;

4. use a contour backfill to eliminate the final highwall;
5. retain the existing watershed boundaries;
6. recontour the portion of the Colowyo Mine property disturbed by mining to produce a topography indicated in the map of the final reclaimed surface (Figure 8). Areas not channelized should be recontoured to a gently undulating topography with numerous small basins;
7. use grade control structures with the appropriate bank protection device to control channel downcutting and bank erosion. Vegetate waterways with densely rooted species.

In the final analysis, the success of a reclamation plan for a surface coal mine rests on three factors. Initially, the recommendations must be based on sound field data and on the experiences with reclamation at other mines. In addition, the design criteria must be consistent with all legal requirements and a prior land use plan which imparts a long-term productivity to the reclaimed surface. Finally, the mining company must make a moral and financial commitment to the restoration of a physically stable landscape. Recognition of these three factors plus the goals and methodology utilized in the derivation of the Colowyo Mine reclamation plan are the prerequisites to improving the technology of surface coal mine reclamation.

FOOTNOTES

1. V.T.N. Engineers-Architects-Planners, Draft Environmental Impact Statement for the Proposed Colowyo Mine (Denver: V.T.N., 1974), 179 pp.

2. V.T.N. Engineers-Architects-Planners, The Reclamation Plan for the Proposed Colowyo Mine (Denver, V.T.N., 1976, 76 pp.

3. Elmore C. Grim and Ronald D. Hill, Environmental Protection in Surface Mining of Coal, Environmental Protection Technology Series No. 670/2-74-093 (Cincinnati, Ohio: E.P.A., 1974), p. 15.

4. Information supplied by the mining engineer at the Edna Mine on September 12, 1975.

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