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Paul M. Boden, Robert J. Garcia, and Mark T. Murphy, 1990, pp. 445-450

in:

Tectonic Development of the Southern Sangre de Cristo Mountains, New Mexico, Bauer, P. W.; Lucas, S. G.; Mawer, C. K.; McIntosh, W. C.; [eds.], New Mexico Geological Society 41st Annual Fall Field Conference Guidebook, 450 p.

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COAL SURFACE-MINE RECLAMATION AT THE YORK CANYON COMPLEX, COLFAX COUNTY, NEW MEXICO

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Abstract—The State of New Mexico, Department of Energy, Minerals and Natural Resources, has approval and oversight authority for coal-surface mining reclamation plans within the York Canyon region of north-central New Mexico. These plans comprise geomorphic and environmental elements of great complexity. Regional drainage is dominated by canyons deeply incised into shallow-dipping, coal-bearing sandstones and shales of Late Cretaceous to early Tertiary age. The biotic communities vary between pinyon/juniper, grassy bottom land, and Ponderosa pine/savanna habitats. The reclamation plan is keyed to an approved post-mining land use, in this case, wildlife habitat and domestic livestock grading. Revegetation, regrading and drainage reconstruction success will be measured in relation to this final goal.

Several problems are present at York Canyon which are generic to reclamation engineering in the arid Southwest. In the West Ridge part of the mining complex, several small sub-watersheds will be impacted by mining. These areas are not environmentally permissive of large-scale surface-water diversion structures. An alternative operation has been approved under NM rule 80-1, "Best Technology Currently Available (BTCA)." Data are being collected from this operation to evaluate the success of the effort and expand our understanding of alternate sediment control. The Department is also attempting, under recent Coal Surface Mining Commission revisions to Rule 80-1, to gather data on rill and gully erosion as a function of slope stability. Initial results of these two investigations are not yet conclusive; however, they do indicate that York Canyon is an excellent candidate for this kind of study and that the geomorphic variables of landscape stability are interactive and complex.

INTRODUCTION

The Pittsburg and Midway Coal Mining Company (P&M) is currently conducting surface and underground coal mining within the drainage of York Canyon, a tributary of the Vermejo River within the Raton coal field, Colfax County, northwestern New Mexico. This mining operation was permitted under New Mexico CSMC Rule 80-1, permit numbers 1-12P, 11-15P and 23-8P. These permits were originally issued to the Kaiser Coal Company and were transferred to P&M in early 1989.

Rule 80-1 requires that coal surface and underground mines shall be reclaimed to specific performance standards and in agreement with an approved mine plan all of which combine to restore the land to its approximate original contour (AOC) and designated post-mining land use. The operator is bonded for all reclamation costs, and regular inspections and enforcement actions are conducted by the Mining and Minerals Division (MMD) of the New Mexico State Energy, Minerals and Natural Resources Department. MMD reviews all permit application materials and issues the final permit under the authority of the New Mexico Coal Surface Mining Commission.

In the case of the York Canyon mines, the unique topography and climate of the Raton coal field (relative to other New Mexico coal fields) causes additional complications. These differences have required imaginative solutions to reclamation problems. In general, the unique geography and geology of the Rocky Mountain coal fields require reclamation which is specific to a tectonically dynamic region (Wells and Rose, 1981). The York Canyon mines are further complicated by a steep, incised topography, a diverse ecological community and a wetter climate, relative to the San Juan or Gallup coal mining districts. This brief description of the York Canyon reclamation program and our nascent research efforts will hopefully highlight the subtle interplay between geomorphology and engineering required by surface-mine reclamation in the arid Southwest.

Geology and geography of the York Canyon area

York Canyon drains a 195 km^2 area located within the Sangre de Cristo Mountains about 40 km southwest of Raton, New Mexico (Fig. 1). The intermittent stream joins the Vermejo River about 3 km downstream of the York Canyon mines. The area is characterized by ridges of mixed conifer forests separated by flat bottomed, pinyon-juniper or grassy alluvial valley floors. Tributary canyons are usually steep-sided

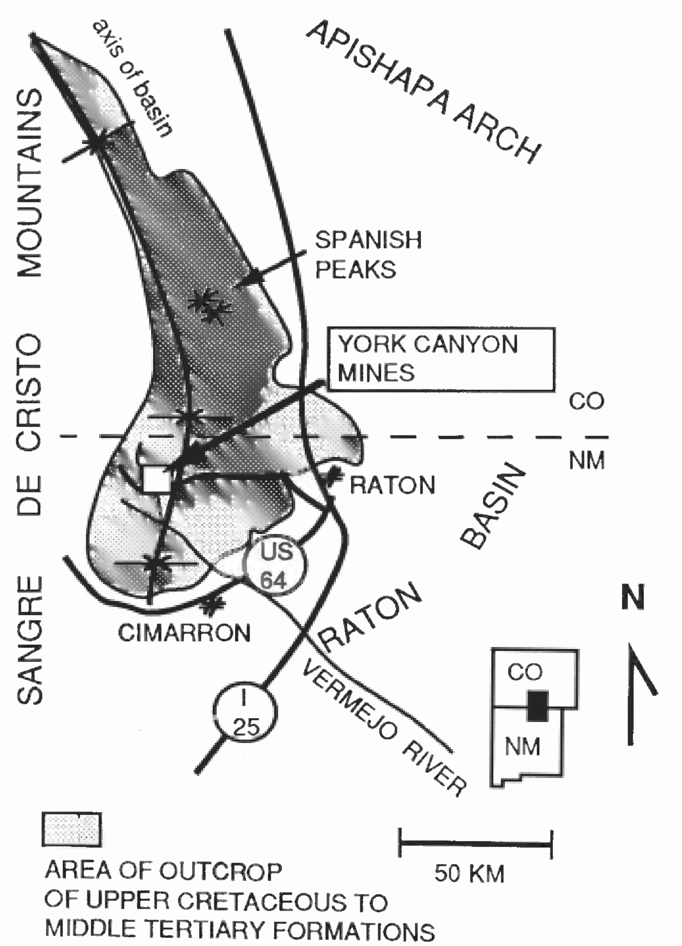

FIGURE 1. Regional structural map for Upper Cretaceous/Tertiary coal-bearing rocks of northern New Mexico and southern Colorado.

and deeply incised. The region is arid; precipitation averages 32.8 cm/y with most falling between May and September. January temperatures average 0° C, and for July, 20°C.

Coal-bearing units of Late Cretaceous age occur throughout the Laramide Raton basin, its axis extending from the Wet Mountains, Colorado southeasterly to the Sierra Grande arch near Springer, New Mexico (Fig. 2). These units include (from earliest to latest) the black, fossiliferous Pierre Shale, the light gray, fine- to medium-grained, calcareous Trinidad Sandstone and the silty to fine-sandy, carbonaceous Vermejo Formation. Both contacts are conformable. The coal seams mined at York Canyon are units of the carbonaceous, silty, sandy, to conglomeratic sequence of the upper coal zone of the Raton Formation which lies across the Cretaceous-Tertiary boundary, unconformably overlying the Vermejo Formation. The arkosic, coarse-grained to conglomeratic Poison Canyon Formation is Tertiary, and its contact with the underlying Raton Formation is laterally gradational. This sequence has been interpreted as the deposits of a generally regressive, Late Cretaceous shoreline, accompanied by the progradation of deltas, crevasse splays and peat-forming swamps. During the early Tertiary, this sequence was quickly buried by fluvial deposits (upper Raton and Poison Canyon Formations). Numerous mafic to intermediate-composition sills, dikes and plugs have intruded the coal-forming sequence during the Tertiary and Quaternary.

Although the York Canyon sequence generally dips in a shallow, easterly direction, a major structure, the Vermejo Park anticline, traverses the area, its axis running in a southerly to southeasterly direction subparallel to the Vermejo River. Several minor faults are associated with this structure and the coal deposits.

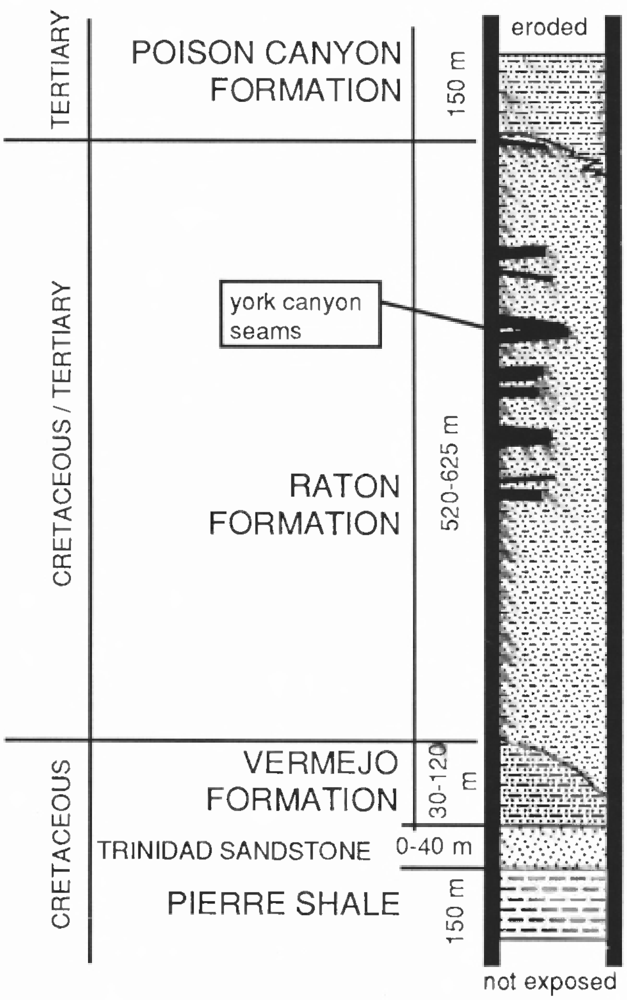

FIGURE 2. Generalized stratigraphic section for units encountered in York Canyon exploratory wells. Descriptions of the units are given in the text.

All of the seams mined at York Canyon are lenticular interbeds within the Raton Formation and represent floodplain or back-swamp environments. York Canyon coal is of unusually high rank compared to other New Mexico fields. Sulfur (0.6%), ash (8.8%) and pyrite are generally low, volatiles are high (35.7%), and the coal is bituminous in rank (14,300 btu/lb) (Pillmore, 1969)

Kaiser Coal Company and P&M have monitored ground- and surface-water quantity and quality in compliance with New Mexico Coal Surface-Mining regulations since the mid-1970's. Mining operations are expected to impact two aquifers, the York Canyon alluvial aquifer and its tributaries and the Raton Formation aquifer. Because of the numerous individual mine permits active within a hydrologically contiguous area, a comprehensive hydrologic impact assessment (CHIA) was required by SMACRA and NM Rule 80-1. Although major impacts are expected to occur in the immediate vicinity of the mine, no measurable effect in quality or quantity is predicted outside of the permit boundaries, and no permanent effect is expected (MMD, 1985; Kaiser Coal Company, 1986).

Mining operations

Coal has been mined in the Raton basin since the late 1800's, primarily in the Koehler, Van Houton and Dawson areas as underground operations (MMD, 1984). In 1966, Kaiser Coal Company began large-scale mining in York Canyon. In 1988, these properties were sold to the Pittsburgh & Midway Coal Company. The York Canyon Complex consists of three active mines, the York Canyon surface mine, the York Canyon underground mine and the Cimarron underground mine. Their permit areas are 2900 acres, 4361 acres and 5114 acres, respectively.

The York Canyon surface mine has an estimated remaining life of approximately five years at a production rate of 1,000,000 tons per year. This mine is a combination loader/truck, shovel/truck and dragline operation. Bulldozers clear vegetation prior to topsoil removal. Topsoil is removed using scrapers and dozers. Benches are prepared for drilling, blasting and removal of the overburden through the loader/truck, shovel/truck or dragline operation. After the overburden has been removed, the coal is cleaned with bulldozers or rubber-tired dozers. The coal is then ripped with dozers, loaded into trucks and hauled to either the preparation plant, the silo preparation facility or the stockpile.

Assuming a production rate of 180,000 tons per year, the York Canyon underground mine has an estimated life of approximately ten more years. Mining began in 1965, and most of the minable coal has been removed. P&M plans to pull the remaining pillars, however, to maximize recovery. Longwall pillars were depleted at this mine several years ago. These pillars were developed with continuous miner sections, and mined under a longwall operation. The remaining pillars will be mined using a continuous miner section. The split and fender method of pillar extraction is used at this mine. This method involves splitting the coal pillar and then taking slices or lifts from the pillar's interior. As the pillar supports are mined and the equipment retreats, the roof caves and fills the void where coal was extracted.

The Cimarron underground mine has an estimated life of 20 more years at a projected annual production rate of approximately 1,500,000 tons per year, market permitting. The Cimarron mine is located approximately 8.3 km north of the other two mines. Coal is mined from the Left Fork seam which is approximately 90 m stratigraphically below the seams being mined at the other two mines (Pillmore, 1976). The mine is a longwall operation in which continuous miner sections develop longwall panel pillars. The continuous miner sections develop headgates, tailgates and starting rooms for longwall panels. Longwall equipment then mines the coal in the panels. This is the most efficient underground mining method in current use. It results in the highest coal recovery with the lowest production costs, while providing a safe working place for the mine personnel.

RECLAMATION PLAN

Baseline studies

Under the approved reclamation plans for the three active York Canyon mines, all surface areas disturbed by, or used to facilitate mining, are to be returned to a condition capable of supporting the designated, post-mining land use of wildlife habitat and livestock grazing. Planned reclamation techniques include regrading the spoil to a design gradient, replacing soil material and planting locally adapted species of trees, shrubs, grasses and forbs. Detailed surveys of landscapes, soils and vegetation were conducted prior to disturbance. Data collected by these surveys are used to establish standards for evaluating reclamation success.

The York Canyon drainage complex includes the main U-shaped channel and multiple V-shaped tributaries. The main drainage has low terraces and flood plains. Total width is generally less than 125 m. The tributaries are spaced at intervals of 100 to 500 m in the vicinity of the mine. These head on steep to gently sloping uplands but have cut through the sandstone near the main channel. This has resulted in steep channel gradients having side slopes of 30° or more. This complex drainage pattern resulted in diverse soil and vegetation.

The detailed soil survey conducted for Kaiser Coal Company (1986) by the Soil Conservation Service indicates that soils on the mine-permit area have developed in materials weathered from sandstone and shale. Soil depth ranges from very shallow on ridge tops to very deep on alluvial materials. Soils mapped include mollisols, entisols, alfisols and inceptisols. Textural families range from fine to loamy skeletal and are mesic or frigid. The soil material has a pH range between 6.0 and 7.5. The genetic horizons are low in salts as indicated by low electrical conductivity, and the sodium adsorption ratios are less than 1.0. Organic matter content of the surface layers is 3 to 6% except for the very shallow soils.

Pre-disturbance quantitative vegetation data were collected between 1979 and 1985. These data were used to select species for revegetation and will be used for revegetation success standards. Thirteen vegetation types ranging from riparian bottomland to mixed conifers were recognized, mapped and documented on the permit area.

Vegetation ground cover, including litter, ranges from 52% to 91%. Rock cover comprises up to 38% of the surface on the pinyon-juniper, oak-brush vegetation type. Production of grazeable vegetation ranges from 754 pounds per acre on grassy tops to 2048 pounds per acre on the riparian bottomland. This converts to a livestock stocking rate of 0.60 to 1.63 animal unit months per acre.

Regrading

The mining company has committed to removing all facilities, structures, etc. and will regrade the entire area within one year after mining ceases. A bond adequate to cover the cost of reclamation from a worst case basis is held by the State. Figure 3 is a photograph taken in 1986 from the east of the West Ridge surface mine showing the various stages of mining, regrading and revegetation. By way of comparison, the revegetated plot at the base of the photo was reclaimed in 1978 (T. Leftwich, oral commun., 1989).

All spoil will be graded to eliminate piles and depressions. Fill material will be placed to minimize effects to ground water and off-site impacts. The pre-mine ridges having angular shoulders with very steep side slopes will be replaced with smoother tops and sides with gentler slopes. The original steep sided canyons and sharp ridges cannot be replaced after the bedrock control has been displaced. The gradient of reconstructed slopes will not be steeper than 3:1 (18°).

Since bedrock no longer controls the topography in post-mine landscapes, terraces designed to slow runoff and direct it to non-erosive outlets are constructed. These features are designed and built so the 8 to 10 m wide terrace is sloped into the hill. By constructing these broad based terraces during slope reconstruction, the steepened front and backslopes common to cut-and-fill terraces are eliminated. The maximum distance between terraces is about 30 m. Rip-rapped downspouts are constructed to carry runoff from upper slopes to stable natural drainages off the disturbed area.

Highwalls will not be left after mining is completed. Coal seams that crop out will be covered with a minimum of 1.3 m of non-toxic, non-combustible material. The regraded spoil is tested to check for any materials potentially toxic to plants or animals. If toxic material occurs, 1.3 m of non-toxic material will be used to cover those areas.

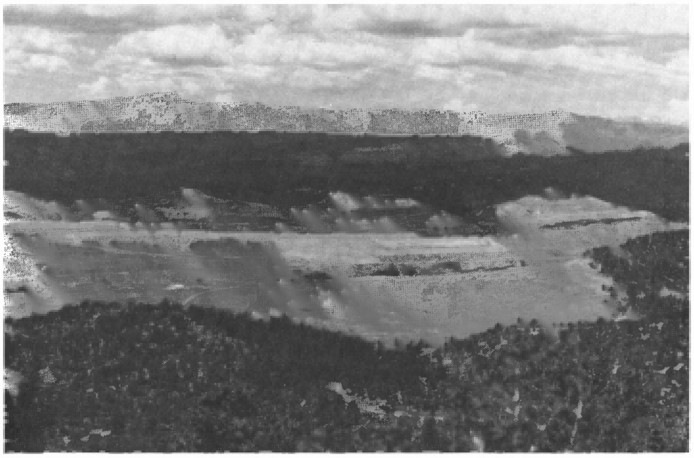

FIGURE 3. View to the west of the York Canyon surface mine taken in 1986 from Road Canyon. Deep canyon at middle distance is the Vermejo River. Dark black patches in the middle are working pits. Orange patches are undergoing regrading and revegetation. Bare patch in foreground is the east bank of York Canyon. Note scrapers and trucks in pit for scale.

After the spoil is brought to design elevation and grade, the spoil is ripped to reduce compaction. Topsoil will then be replaced at depths of 15 to 60 cm depending on location and desired post-mine habitat type.

Drainage reconstruction

To control runoff from the regraded reclaimed lands of the York Canyon surface mine, P&M plans to construct terraces connected with downspouts. The lowest terrace is designed to drain as a diversion. The maximum number of terraces in series will be five. Cross-dikes will be constructed on the terraces every 1900 m. The maximum watershed size can be predicted and would be 0.11 km^2. All downspouts are rip-rapped and designed to handle the discharge of a 10-year, 24-hour storm, in this case, 120.31 cfs. Although the downspout is designed for the above requirements, it will be oversized in most cases. The downspout design is kept generic to simplify the construction process. The lowest terrace is designed to handle the peak flow from a 25-year, 24-hour precipitation event. These terraces will drain at a slight gradient and will discharge into established drainages with rip-rapped spillways.

Revegetation

Replacing the complex vegetative communities that existed prior to mining is not only impractical, it is impossible. Without bedrock control, post-mine landscapes are less complex, more rolling and less angular than pre-mine landscapes. Therefore, 5 post-mine habitat/vegetation types will replace the 13 types that existed on the area prior to mining.

The mining company, after consultation with wildlife and reclamation agencies, decided to replace grassy bottom, grassy top, Ponderosa pine, Ponderosa pine/savanna and talus slope habitat types. The first four habitat/vegetation types are expected to be most beneficial for deer, elk and domestic livestock. The talus slope habitat type will be more beneficial for small mammals and birds. Areas of this type include constructed rock drains, rock outslopes and isolated piles of larger rocks scattered throughout the other types.

Revegetation is tailored to each of the post-mine vegetation types by species selection, which in turn depends on landscape features such as slope, aspect and position. In general, revegetation activities consist of final seedbed preparation, fertilizing, seeding, mulching and, where appropriate, tree planting. Disking to break up larger clods and to break surface crusts is adequate for final seedbed preparation in most places. Seeds are distributed with a drill or by hydro-seeding. Mulch is applied with a blower and is crimped into the soil or tackified with a commercially available emulsion. These operations are followed by tree planting.

Species used are those identified during pre-mine surveys. A seed source does not exist for all forb species. However, when seeds of native forbs are available, these are added to the mix. Seed mixes are formulated to provide a balance between warm and cool season grasses and between grasses and shrubs.

Shrubs are planted by seeding with grasses and forbs. Trees are either bare root or containerized seedlings. Various water harvesting methods are being tested to increase the amount of moisture available for tree seedlings. Trees will be planted at a density of 307 per acre on the Ponderosa pine site and 103 per acre on the Ponderosa pine/savanna site.

The level of success of revegetation efforts will be determined by comparison to pre-mine survey data and technical standards mutually developed by the regulatory agency and the mining company. Revegetation will be monitored throughout the ten-year liability period. An in-depth survey will be conducted during years nine and ten to determine if landscape stability and vegetation is adequate to justify bond release.

RESEARCH PROJECTS

Best technology currently available (BTCA)

Throughout Rule 80-1, the phrase "best technology currently available" is used to designate treatment strategies for overland runoff and/or ephemeral (as opposed to intermittent, perennial and/or thoroughgoing) stream flows. The definition of this phrase is:

PART 1 GENERAL; Sec. 1–5 Definitions

BEST TECHNOLOGY CURRENTLY AVAILABLE—means equipment, devices, systems, methods or techniques which will—

(a) prevent to the extent possible, additional contributions of suspended solids to stream flow or runoff outside the permit area, but in no event result in contributions of suspended solids in excess of requirements set by applicable State or Federal laws; and

(b) minimize, to the extent possible, disturbances and adverse impacts on fish, wildlife and related environmental values, and achieve enhancement of these resources where practicable. The term includes equipment, devices, systems, methods or techniques which are currently available anywhere as determined by the Director, even if they are not in routine use . . . Within the constraints of the permanent program, the Director shall have the discretion to determine the best technology currently available on a case-by-case basis as authorized by the Act and these rules and regulations.

This definition has been interpreted by MMD and the U.S. Department of Interior, Office of Surface Mine Reclamation and Enforcement (OSM) to mean that in some instances, sedimentation ponds and large diversionary structures may cause enough new disturbance to be environmentally counter-productive. BTCA allows the operator and the regulatory agency to investigate alternate sediment control methodologies.

At York Canyon, several discontinuous yet recoverable coal bodies lie along the divide between York Canyon and the undisturbed Vermejo River (Fig. 4). Two of these areas have been included in the York Canyon BTCA program (Kaiser Coal Company, 1988). About 20.3 acres out of a 466-acre sub-watershed of the Vermejo River will be disturbed by one part of the operation and 24.0 acres out of 261 acres by the other. If sedimentation ponds were used, they would have to be constructed at the base of the slope in previously undisturbed terraces to the Vermejo River and would be required to contain the runoff generated from the 10-year, 24-hour event over the entire sub-watershed. The diversions and ponds necessary have been calculated (Kaiser Coal Company, 1988) using USDA-SCS sediment yield and runoff models (Barfield et al., 1983). The additional disturbance predicted is 19 acres for the two areas. The average disturbance (acres) per mined area (acres) for the York Canyon surface mine is 0.06 and for these ponds, 0.15, an increase of 150%.

In the fall of 1988, Kaiser submitted a plan to stabilize erosion and sedimentation using alternatives to ponds and massive diversions. The plan comprises both a treatment and a mining sequence. Background water quality data were collected (single-stage samplers) at the base of each sub-watershed for a year previous to the submission of the plan. In the spring of 1989, after review by MMD and OSM, the plan was approved. The elements of this plan are: (1) stripping sequencing to minimize disturbance in advance of mining; (2) brushing of the surface and the construction of windrows (brush fences) at the perimeter of the disturbed area to reduce overland flow velocities and filter sediment; (3) topsoil stockpiling followed by scraping of the overburden to promote surface roughness and consequent increased infiltration and low overland velocities; (4) design of drilling and blasting benches to drain back into the advancing pit; and (5) regular water quality monitoring at the base of each sub-watershed augmented by passive, single-stage samplers installed immediately down slope of the windrows.

FIGURE 4. Typical view of York Canyon BTCA area. Area includes mixed conifer forest and open, grassy meadows. Bare area in middle background is the typical disturbance anticipated. Note scraper at extreme left for scale. Under traditional reclamation technology, a diversion would be required for the meadow in the foreground.

Data from the first complete season can be compared to the baseline information (Fig. 5). The data are highly scattered, similar to small-sample, sediment yield data collected from reclaimed mine lands throughout the western U.S. (Barfield et al., 1983; Jercinovic, 1984), and a single-season conclusion would be premature. Nevertheless, using a standard, student t-test analysis, no significant difference (95% confidence level) occurs between the baseline data and the first year of disturbance. Note also that this first year probably represents the time of lowest cover and greatest sediment yield. On site, some readjustment of gradient and sediment storage can be seen within the upper tributaries of the main channel similar to the redistribution described from experimental systems (Schumm et al., 1987). This result suggests that

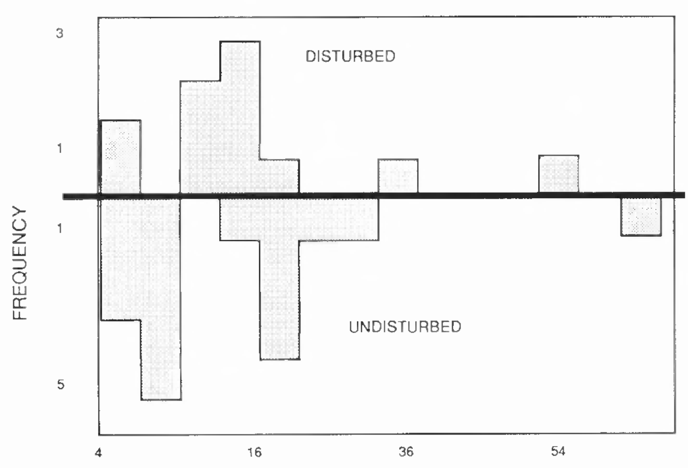

FIGURE 5. Frequency histogram for total dissolved solids from disturbed and undisturbed York Canyon BTCA drainages after one season (1989). There is no significant difference in the means at the 95% confidence level.

York Canyon sub-watersheds are very efficient in adjusting drainage basin storage in response to disturbances and that the natural system rapidly returns to quasi-equilibrium state.

Rills and gullies

During 1989, the New Mexico Coal Surface Mining Commission substantially changed Rule 80-1, 20-106 to eliminate the permissible depth (previously, less than 9 inches) for rills and gullies on reclaimed mine lands. Following the identification of unusual erosion, the new regulations require that MMD determine the long-term stability of a slope before a remedial action is approved. This new approach requires that the individual inspector use criteria for landscape stability which are, at this point, highly qualitative. Due to this need, MMD has initiated a preliminary, slope-stability-research program and intends to solicit funding for full expansion of this project. Such a research program would be designed to answer some of the following questions: How do we predict the nature and extent of gullying on a reclaimed slope and establish its source (design failure vs. natural drainage evolution)? What are the specific parameters (rainfall amount and intensity, slope length, soil shear strength, rock litter, vegetative cover, etc.) which determine this? Are these parameters linearly related to slope diffusion and slope gradient reduction? How do the boundary conditions (baseline adjustments, neotectonics, etc.), in particular the off-permit ones, control the slope dynamics, and which of these are of first-order importance? MMD hopes to integrate both field data, theory and predictive computer modeling for the eventual answers.

As a first step, we have begun to collect erosional data on reclaimed hillslopes at several mines, including the York Canyon surface mine. This project, begun in June of 1989, will accomplish two goals: (1) provide a "first cut" data base to assist inspectors in enforcement of 80-1, 20-106 and establish the scale and scope of the expanded study; and (2) test a variety of field data collection schemes. The second consideration is not trivial; the changes in profile and elevation due to erosion over short time intervals are very subtle. As a first cut, we have adopted two techniques which are currently installed at York Canyon, level sections and erosion pin transects.

The level section was developed by the senior author and colleagues at the Soil Conservation Service, U.S. Department of Agriculture from previous methods for measuring topsoil loss. The system consists of two or more 1.3 cm diameter, 1 m long iron rebar stations driven well below the freeze/thaw depth at either side of a hillslope plot. The tops of the rebar are about the same elevation. A common carpenter's level, fitted with 20 wooden or metal dowel (2.54 cm apart), is placed between the rebar stations, leveled and clamped in place. Each dowel is gently pushed through the level until it makes contact with the ground (rocks are noted on the data sheet). The height of the dowel above the surface of the level is recorded. Measurements are taken after each significant erosional event. In this way a time-depth profile is developed to measure the amount and distribution of sediment removal.

These sections are augmented by erosion pin transects and used at the McKinley mine near Gallup, New Mexico (Wells and Rose, 1981; Jercinovic, 1984). The erosion pins have no universal configuration; the ones used in this study consist of a common galvanized steel spike (0.3 m long) fitted with a 1.9 cm, galvanized steel washer. Each pin is marked with the pin number on the head, shank and washer. Pins are driven into the ground about 5 cm above the surface with the washer resting on bare earth. Care is taken to disturb the ground as little as possible during installation. Distance between pins varies and is measured approximately with a steel or fiberglass tape. Measurements are made between the highest point on the washer and the top of spike if there is a net loss and between the surface of the ground and the top of the nail if deposition has occurred.

At York Canyon erosional monitoring stations were constructed in early 1989 at three locations. Stations consisted of two to three level sections connected by a line of erosion pins. This layout was intended to record both longitudinal, down-gradient sediment transfer and the shape and depth of erosion at a specific point. Precipitation gauges are located nearby and are monitored by P&M staff. As an example, Figure 6 presents the data recorded for one rainy season on a slope known informally as "the bowl." The erosion pins at one of the other York Canyon sites were washed out, and their long-term performance appears to be highly site specific. In some cases the washers armor the soil and result in a pedestaled, biased observation. The level cross sections appear to perform well, although care must be taken that rills do not erode the soil around the base of the rebar stations.

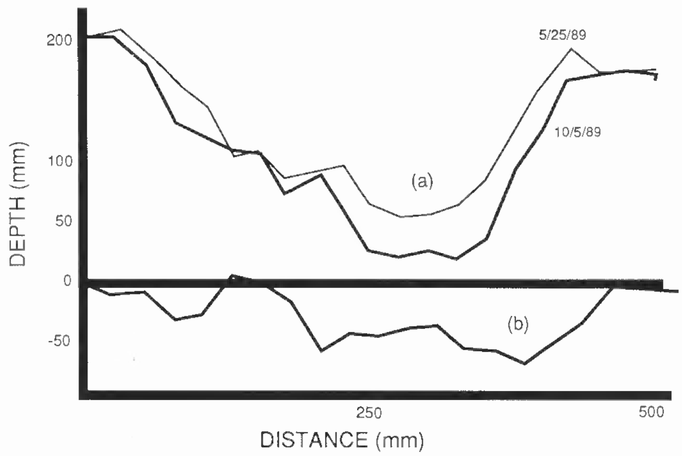

FIGURE 6. Single-season (1989) data from York Canyon erosion plot. (a) Elevations recorded during May and October for level section stations (1–20). Measurements are made from the top of the level (zero datum) to the top of the dowel, the curve following the shape of the gully. (b) Net sediment loss curve for the same section stations.

Despite some encouraging progress, no conclusions can be drawn until many more observations have been accumulated. The ease of installation, low cost and low maintenance associated with these stations allow for a very widespread network throughout the mine (and also the state). Presumably more sophisticated methodology can be installed at key locations following this reconnaissance study.

CONCLUSIONS

The fundamental conclusion offered by this discussion is that the engineering of reclaimed landscapes rests upon the sciences of geomorphology, hydrology and rangeland biology. These disciplines describe the natural and dynamic behavior of the pre-mining landscape. Any successful reclamation effort must design and construct a landscape which conforms to these conditions. The purpose of this article is to describe briefly the York Canyon Complex, outline our research response and stimulate communication on these challenging problems.

ACKNOWLEDGMENTS

The authors thank Richard Koehler of MMD and Michael Coats of P&M who designed the BTCA plan. Tim Leftwich, MMD and formerly with Kaiser Coal Company and Robert Russell, MMD also contributed to this discussion. Reviews by Rich Abitz of IT Corporation and Doug Brookins of UNM were very helpful.

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