Executive Summary

SURFACE REHABILITATION OF LAND DISTURBANCES RESULTING FROM OIL SHALE DEVELOPMENT

C. Wayne Cook
Study Coordinator

June 1974

COLORADO WATER RESOURCES
RESEARCH INSTITUTE

Colorado State University
Fort Collins, Colorado

Information Series No. 11

Executive Summary

SURFACE REHABILITATION OF LAND DISTURBANCES RESULTING FROM OIL SHALE DEVELOPMENT

C. Wayne Cook

Study Coordinator

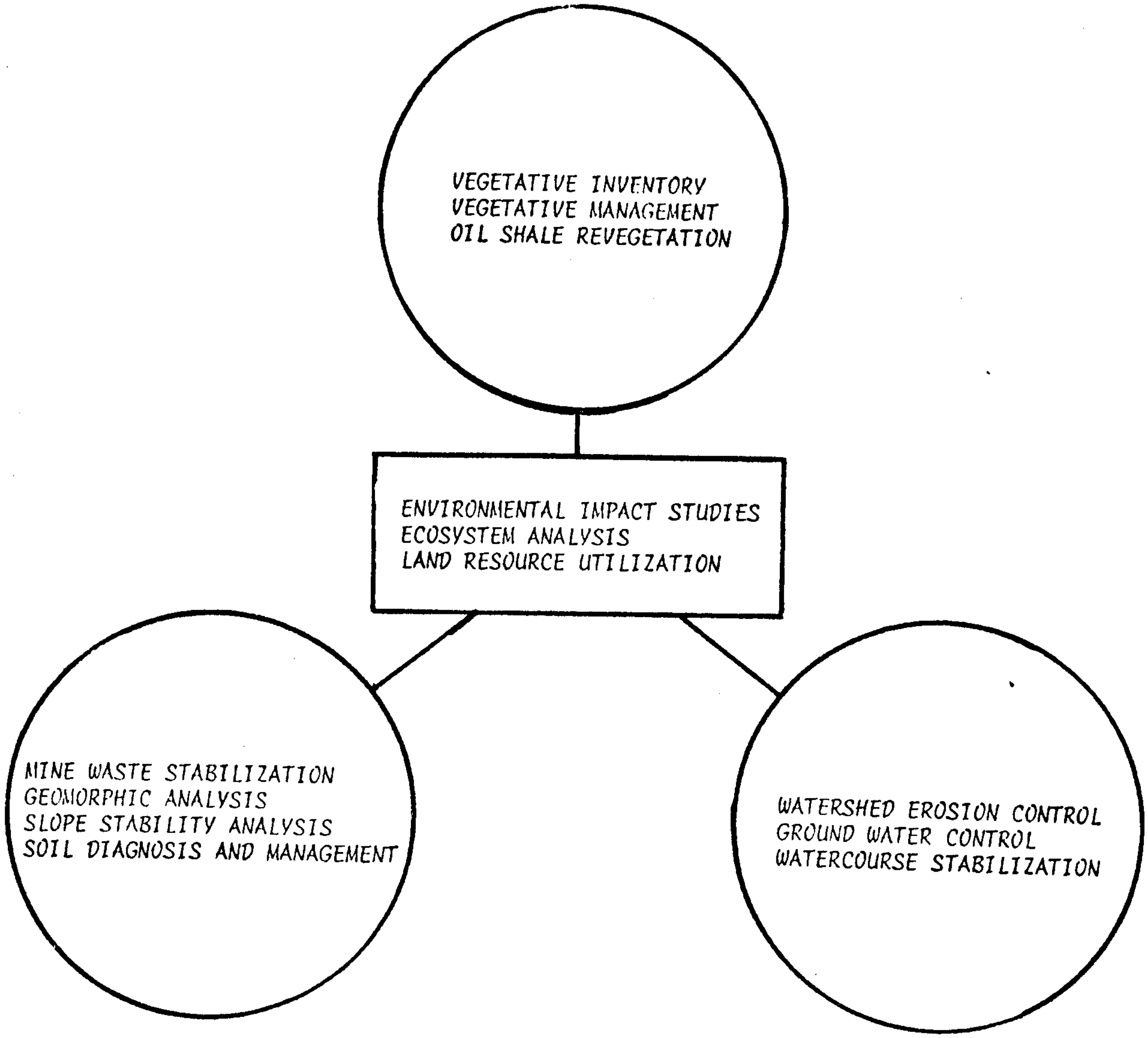
June 1, 1974

The work upon which this summary is based was supported, in part, by funds provided jointly by the State of Colorado, the U.S. Department of Interior and the Petroleum Industry and administered by the Colorado Department of Natural Resources. The full report is available at $10 per copy from the Colorado Water Resources Research Institute.

COLORADO WATER RESOURCES RESEARCH INSTITUTE
Colorado State University
Ft. Collins, Colorado 80523

Norman A. Evans, Director

MINE WASTE AND DISTURBED LAND RESTORATION



COLORADO STATE UNIVERSITY RESEARCH TEAM

Reclamation - Revegetation - Stabilization

W. A. BERG
Revegetation of mine tailings and spoils
Soil-plant relationships on range and forest lands

J. A. CAMPBELL
Stratigraphy and sedimentary petrology
Applications of statistics and computer science to geology

C. W. COOK
Land resource utilization

N. A. EVANS
Irrigation engineering
Drainage and salinity control
Ground water mechanics

R. D. HEIL
Soil survey and land classification
Land use planning and management

E. V. RICHARDSON
Experimental fluid mechanics
Fluvial hydraulics
Stream morphology

S. A. SCHUMM
Geomorphology
Sedimentation

P. SIMS
Plant ecology
Animal nutrition

W. D. STRIFFLER
Watershed management
Forest hydrology

C. TERWILLIGER, JR.
Soil-plant relationships
Biometry and quantitative ecology

R. T. WARD
Grassland and alpine ecology

TABLE OF CONTENTS

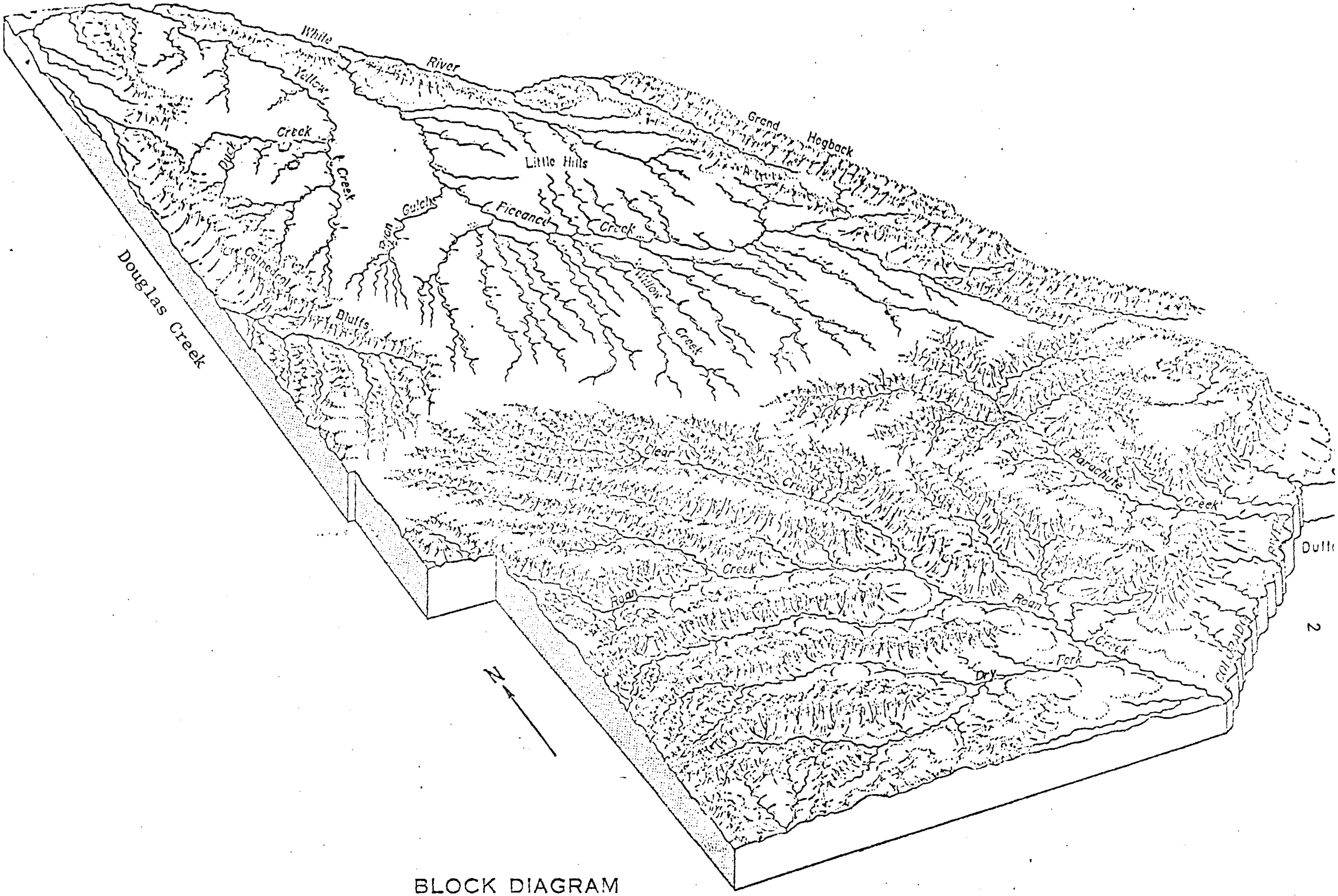
GEOMORPHOLOGY

The Piceance Creek structural basin is located in northwestern Colorado. It is a regional feature about 95 miles long and 50 miles wide. Part of this structural basin forms a distinct physiographic unit, the Roan Plateau, bounded on the east by the Grand Hogback, on the south by the Colorado River and the Book Cliffs, on the west by Douglas and Salt Creeks and the Cathedral Bluffs, and on the north by the White River (Figure 1). This is the Piceance Creek oil shale area of Colorado, and it occupies the easternmost portion of the Tavaputs Plateau, which is part of the Uinta Basin Section of the Colorado Plateau Physiographic Province.

General Geomorphology

The Piceance Creek area can be subdivided geomorphically into two parts, the boundaries of which are defined by the drainage divides between the Yellow and Piceance Creeks drainage basins and the Douglas, Roan and Parachute Creeks drainage basins. The canyons and steep escarpments of the Douglas, Roan and Parachute Creeks drainage basins are in sharp contrast to the more subdued topography of the Piceance Creek and Yellow Creek Basins on the plateau which comprises the greatest part of the area.

That portion of the area west of Cathedral Bluffs in the Douglas Creek basin is rugged and not of easy access. Dendritic drainage patterns are incised into deep valleys, and V-shaped valleys with narrow, flat alluvial floors are typical. The gradients of the tributaries to Douglas Creek are steep. For example, Philadelphia Creek rises at an altitude of 8000 feet and enters Douglas Creek at an altitude of 5800 feet. The 2200 feet of fall occurs over an airline distance of from 4.5 to 5.0 miles. These channels are efficient conveyors of water and sediment to Douglas Creek. This is especially true because the alluvial floor of each valley is trenched by a gully.



BLOCK DIAGRAM

Figure 1. Physiographic diagram of Piceance Creek area. For locations, see Fig. 1. (from Coffin et al, 1971)

Douglas Creek itself has incised into the alluvium of its valley, and this incision is responsible for the rejuvenation of the tributaries and their present condition. This incision probably occurred during historic times, because near the junction of East and West Douglas Creeks a small log cabin is partly buried in the alluvium of East Douglas Creek. This cabin is probably less than 80 years old, and its door fronts directly on a 20-foot drop into the deep gully of East Douglas Creek. There appears to be little doubt that the incision of Douglas Creek has occurred since the construction of this cabin. The valley floors of this region are fragile, and where they are untrenched, they are susceptible to erosion. In the Douglas Creek area, erosion of the valley floors is rapid, and large quantities of sediment are delivered to Douglas Creek and thus to the White River itself.

To the south, Roan and Parachute Creeks deeply dissect the Roan Plateau to form steep-walled canyons that widen sufficiently downstream to permit farming of the valley floors. Total relief in the Roan Creek Basin is about 4000 feet. The steep cliffs and escarpments flanking the Roan Plateau should be susceptible to mass movement or landslides, and recent mapping has produced evidence of landslides along the Cathedral Bluffs and in the Roan Creek drainage basin.

On the plateau the topography is less rugged, and slope erosion processes characteristic of semiarid regions are dominant. Drainage patterns on the plateau are controlled at least in part by the dip of the Evacuation Creek member of the Green River Formation, and the alignment of headwater tributaries suggests a major control of their orientation and spacing by fractures.

The streams on the plateau occupy valleys that are very different from those in the Douglas, Roan and Parachute Creek drainage basins; they are less deep, and they have flat floors, which may or may not be incised.

Unlike Douglas Creek, the valleys do not everywhere contain a well-defined channel, but discontinuous gullies are common. The fact that the channels are not continuous means that much of the sediment conveyed through these discontinuous gullies is retained within the basin and does not reach White River or Piceance Creek. For example, Ryan Gulch is trenched only near the junction of several of its major tributaries, but downstream there is no well-defined channel.

The development of discontinuous gullies, their coalescence to form arroyos, and the eventual healing of these channels by renewed deposition is a sequence of events that can be readily documented throughout the western United States. Therefore, the apparent stability of the alluvial valley-fill deposits in the area is deceptive, and the current condition of sediment storage could change quickly to major export of sediment with serious downstream consequences if and when the drainage lines become continuous. That is, although the channels and the valleys of the plateau at present do not appear to deliver appreciable quantities of sediment downstream, the valley floors are inherently unstable and release of water into these chnnels could trigger a dramatic erosional response.

The flat-floored valleys are separated by convex or flat-topped ridges. At present the erosion rates on these interfluve areas range from slight to critical with three percent of the areas in the Yellow Creek Unit subjected to slight erosion, 67 percent to moderate erosion and 30 percent to critical erosion, according to an evaluation of present erosion conditions by the Bureau of Land Management. The obvious effect of slope aspect is important, with north-facing valley sides being better vegetated, gentler and less susceptible to erosion. South- and west-facing slopes and valley sides are steeper, less well vegetated and obviously more vulnerable to raindrop impact and surficial runoff. The north-facing slopes will be subjected to more cycles of freeze and thaw during the year, and soil creep probably occurs on these slopes. The asymmetry of some valleys apparently is the result of these very different erosion processes and rates of erosion on slopes of different aspect.

The geomorphology of the Piceance Creek area is not unusual. The canyon and plateau topography is similar to that over large areas of southwestern United States. However, during development of the oil shale resource and during rehabilitation of the area, two aspects of the geomorphology of the Roan Plateau could be significant. These are valley floor stability on the plateau proper, and mass movement or landslides in the canyons and along the cliffs. The geomorphic investigations were directed toward a better understanding of these problems. Another important aspect of the geomorphology of the region is the rate at which modern erosional and depositional processes proceed. A continuing program of erosion measurements is being carried out by the Water Resources Division of the U. S. Geological Survey, Denver, Colorado.

Valley Floor Stability

Channels are not continuous in the drainage systems of Yellow and Piceance Creeks. In some areas the valley floors have no channel, whereas in others rapidly-eroding gullies have trenched the alluvium of the valleys. Because the gullies are discontinuous, much of the eroded sediment is not transported into the main channels. However, during development of the oil shale resources, or during rehabilitation, it is possible that increased runoff, due perhaps to introduction of waste water or ground water into the valleys, will precipitate a period of accelerated erosion. Studies in these valleys show that gullying begins on the steepest parts of the valley floor. This seems to be characteristic throughout semi-arid and arid regions. In addition, it was possible to define a critical valley slope for a given drainage area above which the valley alluvium is unstable. This relation is valid only for drainage areas larger than about four or five square miles, but it is possible that it will be useful in locating those areas of potential instability where future gullies will develop.

That is, when valley slope is plotted against drainage area for both gullied and ungullied reaches of these valleys, a line can be drawn which separates the eroding from the non-eroding valleys (Figure 2). This line represents a slope threshold for a given drainage area above which the valley floor is unstable. Locations that plot near the line or above it, and as yet are not gullied, must be considered incipiently unstable and liable to failure during a major storm.

Identification of these valley reaches will permit the land manager to utilize conventional methods of erosion control to prevent failure of the valley floor. Hence, although hydrologic data are not available and drainage area is used as a surrogate for runoff, identification of valleys that will be most affected by man's influence in the Piceance Creek area is possible. If, through vegetational destruction or the need to dispose of groundwater, water is introduced into the ephemeral-stream channels, then the presently-stable valleys, which now plot below the threshold line, will in effect be rendered unstable. That is, increase in runoff will be similar to an increase of drainage area. If the valley plots well below the threshold line, and if care is taken that the water is not concentrated, then only slight enlargement of downstream channels will result. However, if a point is shifted so far that it crosses the threshold line, then the valley floor may fail, and a through channel will develop, which will convey the increased discharge and large quantities of sediment downstream. This type of erosional modification

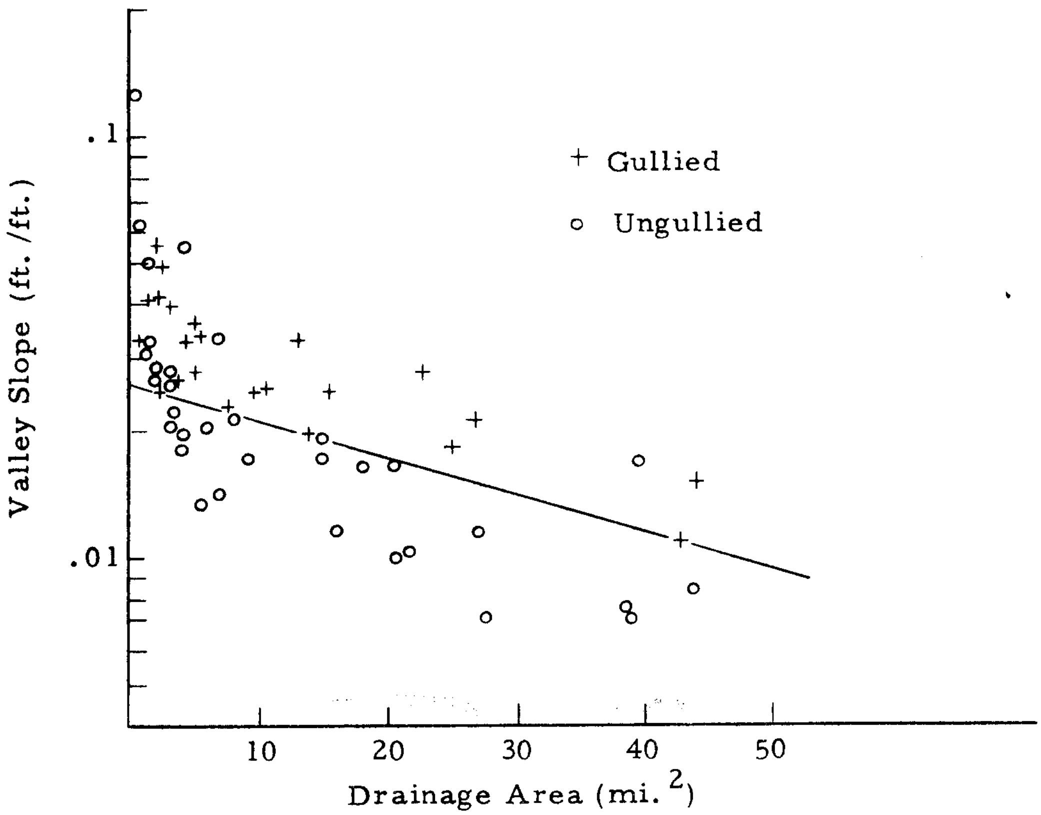


Figure 2. Slope-area relationship for gullied and ungullied valleys in the Piceance Basin.

of the valleys must be avoided because the downstream consequences of high sediment export will be serious.

Landslides

Concerning the problem of slope and cliff stability, field observation in the canyons of Roan Creek reveals that mass movement processes, particularly landslides, have played a major role in the development of the rugged topography of that area. Small rock falls and minor debris and rock slides have contributed material to the extensive talus slopes of the Parachute Creek basin, and talus is accumulating now in both Parachute and Roan Creek drainage basins. Large slumps and rock and debris slides, coupled with normal fluvial erosion and deposition, have occurred in the past to form a complex landscape of sheer cliffs, benches and hummocky terrain in the deep canyons cut into the Roan Plateau by Roan Creek. Because water significantly aids in the genesis of landslide development, most activity probably occurred during times of more favorable moisture conditions, as large-scale activity is not occurring at present.

The distribution of the major landslides is of considerable interest because they are common in the Roan Creek Basin but absent in the Parachute Creek Basin. Within these two adjacent drainage basins, relief, climate and vegetation are similar and, therefore, the distribution of slides must be attributed to variations in the lithology and structure of the rocks exposed in the canyon walls.

Although many large landslides are associated with the outcrop areas of the Wasatch Formation and especially the Lower Shaly Member of the Green River Formation (which does not appear in the Parachute Creek basin), it is the overall less-resistant character of all the rocks deposited on the margin of the Piceance Creek structural basin that is of most significance in explaining landslide distribution.

For example, rocks of the Roan Creek area have a lower organic content, a high content of coarser sediment (clastics) and a large content of unstable clay minerals. Thus, formations that were deposited near the edge of the Green River Formation Lake (Roan Creek area) are inherently weaker than those exposed nearer the axis of the Piceance Creek Basin (Parachute Creek area). Therefore, areas of landslide susceptibility and past major slides are located around the flanks of the basin in Roan Creek and along Cathedral Bluffs. Within these areas, slides frequently occur where fractures parallel the cliff face and where the dip or slope of the rock units is toward the cliff face. These slides are the result of past climatic conditions, and the cliffs are relatively stable at present. However, if during extraction of oil shale or during rehabilitation of the area water is introduced into these potentially unstable areas, or if material is removed from the base of slopes that show evidence of past episodes of instability, the possibility of creating new slides or reactivating old slides is substantial.

THE NATURAL VEGETATION IN THE LANDSCAPE OF THE COLORADO OIL SHALE REGION

Introduction

The eventual return of each mined oil shale site to a condition permanently compatible with the general landscape in which it rests must be the objective of all reclamation and revegetation work in the Piceance Basin. This does not mean, of course, that each disturbed site must be restored to its pristine condition, but only that the landscape be returned to a permanently-functioning, and self-regulating system. To carry this out with sufficient control, manageability, and predictability requires more detailed ecological knowledge than is represented by floristic and agronomic insights. This report concerns understanding landscape relationships in the Piceance Basin toward the end of providing ecological knowledge, particularly with regard to natural vegetation. A first approximation classification scheme of the vegetation of this region is present first, followed by a discussion of the ecological properties of this vegetation.

Major Plant Communities

A catalog of 18 easily recognizable community types is given in Table 1. These types were derived without quantitative data and so must be considered tentative. The sequence of presentation progresses roughly from low to high elevation types. BOTTOMLANDS, which include the valley floors and alluvial fans, are areas of erosional accumulation, which receive water both from precipitation and runon. UPLANDS, the hillsides and ridges, are areas of erosional depletion, where precipitation is the only source of water and runoff exceeds runon.

An idealized description of the vegetational features on the basin landscape is presented in Figures 1 and 2. The vegetation patterns of the northern and southern regions have been abstracted in the figures. Foregrounds represent the lower eleveation; the backgrounds represent the higher elevations nearer drainage divides. The vegetational categories are named to correspond with Table 1.

Patterns of Ecological Relations

To understand the ecological system, it is important to know the species composition of the origninal site, the proportionate amount of each species present, and to recognize that this composition may vary over the landscape even within the same community type. For example, low elevation communities, dominated by juniper and pinyon pine on clayey soils not only have a different species composition from high elevation, sandy soil, juniper-pinyon groves, but these species occur in different amounts. Juniper is far more prevalent

Table I. A CLASSIFICATION OF THE NATURAL VEGETATION OF THE PICEANCE BASIN. The names in parentheses identify the mapping units of Terwillinger and Cook in this publication. Vegetation types are arranged from low to high elevations. See Figs. 1 and 2 for landscape positions of the types.

I. BOTTOMLANDS. (*Bottomlands*; includes A, B and C)

These are areas of erosional deposition.

A. Riparian Woodland.

Occurs along the stream sides of Roan and Parachute Creeks, dominated by cottonwood, boxelder and chokecherry and usually heavily grazed.

B. Big Sagebrush Shrubland.

Well drained, broad flat valley bottoms and alluvial fans with little salinity are dominated by big sagebrush which reaches heights of 2m and canopy covers of 75%. Rabbitbrush, shad-scale and fringed sage are common shrubs. Indian ricegrass and wheat grasses occur in the understory.

C. Greasewood Shrubland.

Broad, flat valley bottoms with high salinity in surface soils are dominated by greasewood. Water table is near soil surface. Rabbitbrush and big sagebrush may be important, but disappear with increased salinity. Shrubs are usually 0.5-2.0m tall.

II. UPLANDS.

These are areas of erosional depletion.

D. Shad-scale Shrubland. (*Desert Shrub*)

Steep and dry hillsides, particularly those with southern exposure and shale outcroppings, support an open, low (0.25-0.75m) shrubland dominated by shad-scale. Indian ricegrass is important and is sometimes co-dominant.

E. Hillside Fringed Sage and Grassland. (*Not Mapped*)

Very steep hillsides with sandy and unstable soils support a low shrubland dominated by fringed sage and Indian ricegrass. Big sagebrush and rabbitbrush are important. Cover less than 20% and shrubs less than 0.5m tall.

F. Big Sagebrush Shrubland. (*Upland Big Sagebrush*)

Clear dominance of big sagebrush, although considerable visual variation occurs within the unit, from ca 1,800-2,500m (6,000-8,000 ft.). Big Sagebrush Shrubland is found on soils deeper than those which support Pinyon-Juniper Woodland and Mixed Mountain Shrubland.

F_1. Low Elevation Big Sagebrush Shrubland. Below 2,000m (6,500 ft.), big sagebrush is less than 0.5m tall. Soils are aridisols, the shallowest of the Big Sagebrush series. Big sagebrush is always the clear dominant but shad-scale and spiny horsebrush are important; winter fat is important if shales are present and greasewood is important if the soils are saline. Understory is sparse.

F_2. Mid Elevation Big Sagebrush Shrubland. On rolling uplands between 2,000-2,300m (6,500-7,500 ft.) big sagebrush is 0.5-0.7m high; more water is available here than at lower elevations. Soils are moderately deep mollisols. Shrubs are less conspicuous than in F_1 or F_3; Junegrass, beardless wheat grass, needle-and-thread, Indian ricegrass and western wheatgrass dominate the understory.

F_3. High Elevation Big Sagebrush Shrubland. Above 2,285m (7,500 ft.) big sagebrush is 0.7-1.0m high and is accompanied by bitterbrush, serviceberry, mountain mahogany and snowberry. Grasses are Kentucky bluegrass, needle grasses, brome grasses and Idaho fescue. Soils are deep mollisols.

F_4. Big Sagebrush Shrublands of Cliffs and Rocky Breaks. Occurs at intermediate elevations and in pockets of deep soil. Soil moisture permits species composition similar to High Elevation Big Sagebrush Shrubland.

G. Mixed Mountain Shrubland. (*Mixed Mountain Shrub*)

Gambel's oak and serviceberry dominate at elevations of 2,100-2,400m (7,000-8,000 ft.) on deep mollisols, achieve heights of 3m or more, and are restricted to gullies and northerly exposures. Oak requires more moisture than serviceberry, but the species often occur together. Mountain mahogany is important through this series.

G_1. Oakbush Shrubland. Gambel's oak is restricted to lower slope positions of upper Piceance, Roan and Parachute Creeks. Canopy cover is 80% or more and reaches 3m in height and 10 cms. in diameter. Associated shrubs are mountain mahogany, chokecherry, snowberry, rose and big sagebrush. Wheat grasses, Indian ricegrass, fringed sage lupine and needle-and-thread form the understory.

G_2. Serviceberry Shrubland. The type is widespread throughout the Piceance country at mid and upper slope positions on north-facing hillsides. Canopy 80% or more and up to 3m tall. Shrubs are serviceberry, mountain mahogany, chokecherry, snowberry, juniper, big sagebrush and rabbitbrush. Wheat grasses, bluegrasses, needle-and-thread, balsamorrhiza, Indian ricegrass, lupine and fringed sage are in understory.

H. Pinyon-Juniper Woodland (*Pinyon-Juniper Woodland*)

Pinyon pine and Utah juniper dominate at 1,850-2,300m (6,000-7,500 ft.). Pinyon-Juniper Woodland is found on soils shallower than Big Sagebrush Shrubland but the types intergrade. Variation in the species composition is related to elevation and soil parent material. Decrease in wild fires during the 20th Century has increased the accumulated leaf litter and repressed productivity, especially in the High Elevation Pinyon-Juniper Woodland (H_2).

H_1. Low Elevation Pinyon-Juniper Woodland. Below 2,100m (7,000 ft.) the soils are dry, poorly developed aridisols. On shales, Utah juniper is the only tree but stunted big sagebrush, bitterbrush and mountain mahogany are present. The understory consist of scattered and stunted Junegrass, beardless wheatgrass, needle-and-thread, squirrel tail and Indian ricegrass. On sandstone, Utah juniper is joined by pinyon pine. Many shrub and herbaceous species of Mid Elevation Big Sagebrush Shrubland (F_2) are prominent. Plant productivity is much higher and soil profiles much better developed here than on shales. As soils deepen, plant composition grades toward Mid Elevation Big Sagebrush Shrublands (F_2).

H_2. High Elevation Pinyon-Juniper Woodland. Above 2,100m (7,000 ft.) pinyon pine becomes the dominant tree. Differences in species composition and productivity with parent materials are minimized here. The soils are well developed mollisols. The shrub layer is dominated by big sagebrush, rabbitbrush and bitterbrush. As soils deepen, this type tends to grade into High Elevation Big Sagebrush Shrubland (F_3).

H_3. Pinyon-Juniper Woodland on Cliffs and Rocky Breaks. On these sites, H_1 and H_2 become stunted. The shrub and herbaceous layers are poorly developed; they are similar in species composition, but not productivity, to Pinyon-Juniper Woodlands at similar elevations. When pockets of deep soil accumulate here, an appropriate elevational Big Sagebrush Shrubland (F) will dominate.

I. High Elevation Grasslands. (*High Elevation Grasslands*)

Shallow and rocky to gravely soils at 2,440-2,750m (8,000-9,000 ft.) on the wind swept ridges of Cathedral Bluffs are dominated by high altitude grasslands. The principal species are bluegrasses, Junegrass and Idaho fescue. Rabbitbrush and burrow weed are common shrubs.

J. Douglas Fir Forests. (*Forests*)

This type is restricted to gullies and north facing slopes at 2,400-2,500m (7,500-8,000 ft.) and occupies a very small proportion of the total landscape. Douglas fir forms closed canopy stands with trees of 30 cms. diameter. Ponderosa pine occurs with Douglas fir. The shrub layer is dominated by serviceberry, chokecherry, snowberry, mountain mahogany and rose. The herbaceous layer is poorly developed.

K. Aspen Forests. (*Forests*)

At 2,400-2,500m (7,500-8,000 ft.) steep coves with northerly facing slopes are dominated by Aspen Forests. These forests are better protected from solar radiation and wind than Douglas fir forests. The Aspen Forests have a closed canopy and aspen often attain diameters of 20 cms. There is some aspen reproduction. These forests have a lush forb, grass and shrub understory fairly typical of aspen stands throughout the western slope. The principal shrubs are oak, big sagebrush, serviceberry, snowberry and common juniper. The principal herbaceous species are sedge, bluegrasses, a native timothy, fescue, Indian paintbrush and bluebell. Aspen Forests are widespread throughout the Piceance Basin but each site is usually restricted to a few acres.

on low elevation, dry sites while pine becomes the dominant on high elevation sites with moderate rainfall.

The variations in the number of species present in a community, and between communities, are important to revegetation since the appropriate levels of diversity must be returned to each reestablished community. Mixed shrub communities, for example, are dominated by five, six, or even more species and are obviously more diverse than some sagebrush communities dominated by only big sagebrush. Differences in herbaceous and shrub diversity in the basin are striking.

Productivity of plant biomass is important for three reasons relevant to rehabilitation: 1) addition of organic matter to the reclaimed system; 2) primary production available for herbivores; and 3) soil protection. Without the vegetation cover, erosion will increase.

Besides the kinds and amounts of plants present in a community, the distribution of plant biomass lends form (physiognomy) to the vegetation. This form is dependent upon: 1) life forms of the constituent species; 2) horizontal distribution of each species; 3) association between species in their horizontal distribution, and 4) development of stratification in a community.

The oil shale region is large enough to include differences in the plantscapes on a geographic scale. The southern region (Figure 3) has more land area within the arid climatic zones and has a greater relief, and, therefore, a "longer" topographic gradient, than does the northern landscape (Figure 4). Differences in relief, exposure, and elevation account for the large part of the vegetational variation in the basin and suggest that moisture and substrate development are the principle gradients to which vegetation responds.

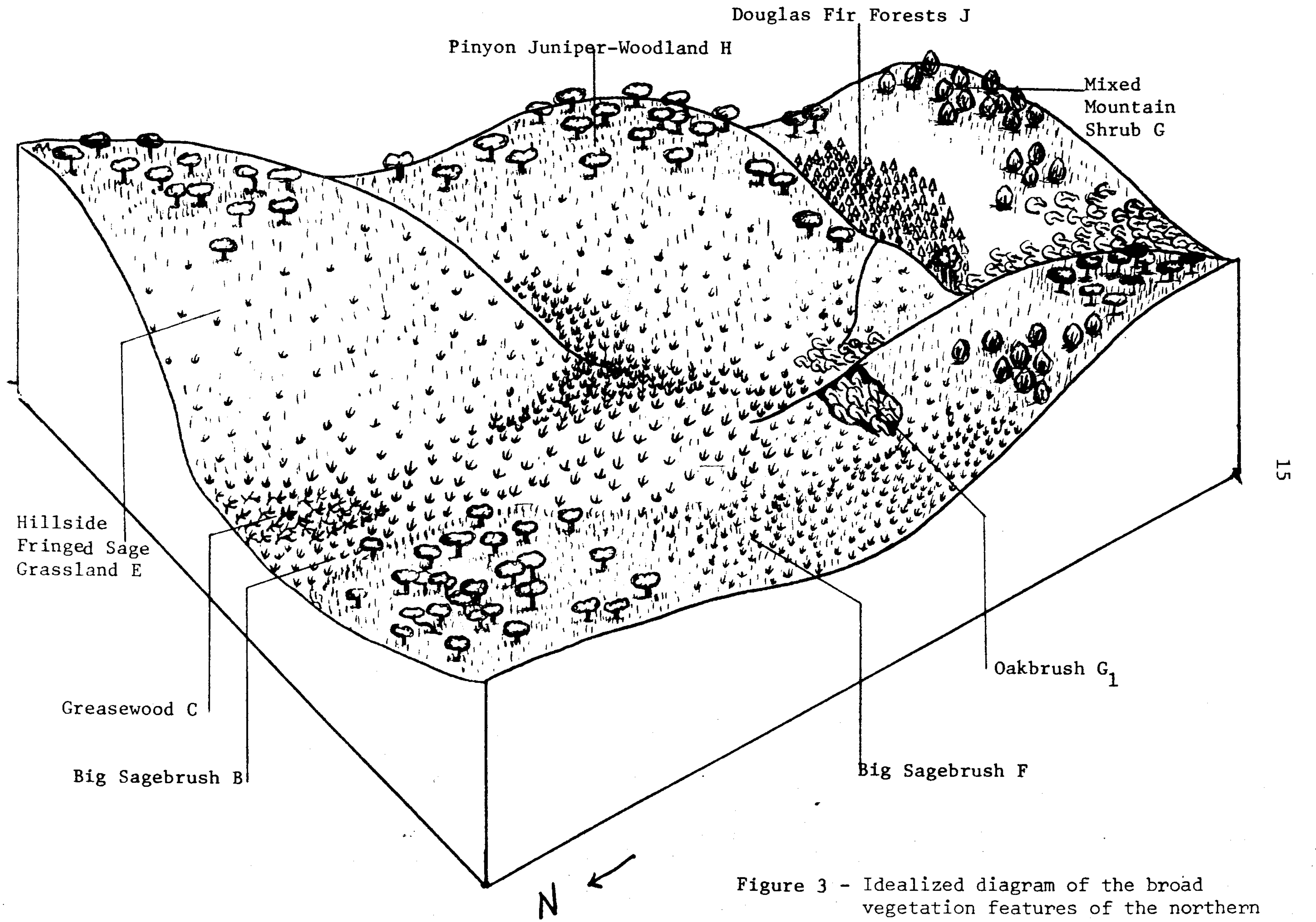


Figure 3 - Idealized diagram of the broad vegetation features of the northern part of the oil shale region. Community names and letter designation correspond to Table I.

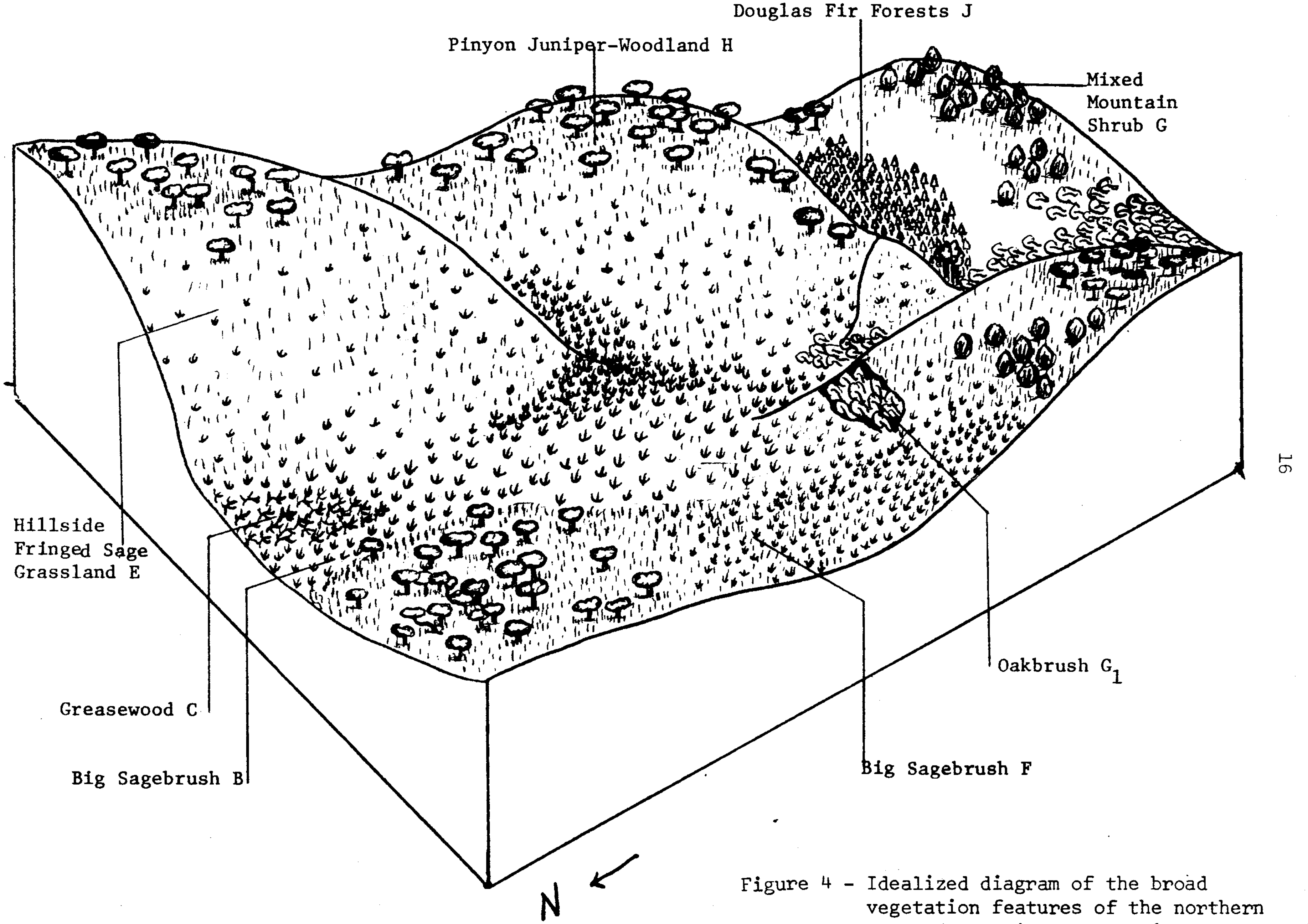


Figure 4 - Idealized diagram of the broad vegetation features of the northern part of the oil shale region. Community names and letter designation correspond to Table I.

Reclamation and revegetation of natural plant communities in the basin suggest two areas of concern. First, evaluation and quantification of the vegetation to be replaced must be made in terms of the ecological properties listed above. At present these data are not available. Second, the technology of compliance to these aspects of vegetation needs to be worked out. Quantification of the vegetation and detailed examination of the environmental factors affecting that vegetation are the next steps to be taken in understanding the ecological properties of the basin.

NATURAL AND ARTIFICIAL REHABILITATION OF DISTURBED SITES IN AN OIL SHALE AREA

Natural Rehabilitation

A knowledge of natural rehabilitation patterns and lengths of time required for successions is needed in order to plan effectively for rehabilitation of areas disturbed by extraction of oil shale or coal reserves. The main thrust of this study was to determine such natural rehabilitation patterns in various ecosystems comprising the Piceance-Yellow Creek Basin and Roan Plateau in western Colorado, to review the literature and to make recommendations concerning artificial rehabilitation.

The time required for natural succession from apparent bare soil to a closed plant community will depend primarily upon the general climate of the area, the soil material available as a plant growth medium and the topographic features with respect to degree and aspect of slope. Natural secondary succession could conceivably require from 20 to 25 years or even 100 years in some areas of the oil shale study area.

Rainfall between 20 and 25 inches annually is perhaps optimum. Soils of a sandy loam texture with rather high organic matter where the topography is flat would complete the natural succession processes in a comparatively short period if parent seed sources were readily available. However, desert areas of heavy, sterile soils receiving only five to six inches of precipitation annually would conceivably require 50 to 100 years or more for complete succession. The natural processes of ecological succession are further hampered in may desert areas by the absence of parent seed sources and the presence of salts in the soil that are toxic to plant growth.

Seeding to perennial grasses such as crested wheatgrass speeds up succession by establishing a perennial grass-weed stage in a relatively short period of time. This stabilizes the area rapidly and favors the invasion of desirable perennial native forbs. Reseeding also reduces the rate of shrub reinvasion and reduces the density of shrubs during the period of succession.

The broad ecosystems in the study area, defined by present dominant vegetation are: desert shrub, upland sagebrush, bottomland sagebrush, pinyon-juniper, mixed mountain shrub, grassland and forest. The most important of these, based on area covered, are upland sagebrush, pinyon-juniper and mixed mountain shrub.

Data on succession were obtained during the summer of 1973 by sampling the vegetation on areas which had been subjected to various types of disturbance at various times in the immediate history of the area. Vegetation composition was determined by estimating weight and expressing percent composition on a weight basis for each species which comprised at least one percent of the composition. The average results reported are based on a relatively small sample from the various ecosystems and types of disturbances. Succession occurred in a biotic environment which included grazing by domestic livestock and big game animals, especially deer.

The study area was divided into low elevation, high elevation and bottomland sagebrush ecosystems for analysis purposes. Disturbances were classified into three types: 1) areas in which vegetation and soil had been completely disturbed such as pipelines and drill sites; 2) area disturbed by fire; and 3) areas disturbed by chaining. The last two disturbances occurred only in the pinyon-juniper ecosystems.

Plots 9.6 square feet in size were used to sample the vegetation on various types and ages of distrubances in the study area. A weight estimate method was used to obtain total weight per plot. The percent composition contributed by each species was then estimated. Composition data were summarized by low elevation, high elevation and bottomland sagebrush ecosystems.

Succession Following Complete Disturbance

Following complete disturbance of vegetation and mixing of the soil, all ecosystems progressed through annual forb, grass-forb and shrub-grass stages of succession. The shrub-grass stage developed in about 17 years in low elevation ecosystems and in about eight years in the high elevation ecosystems. The common pioneer forb on all areas was Russian thistle, often accompanied by some species of mustard or forage. The shrub component of the shrub-grass stage was rabbitbrush in low elevation ecosystems, big sagebrush and greasewood in bottomland sagebrush, and big sagebrush, snowberry and serviceberry in high elevation ecosystems.

The low elevation ecosystems progressed from an initial annual forb community to a perennial grass community after about eight years. Following succession for a period of 15 to 17 years a shrub-grass community had developed.

An annual forb community developed on the bare area following disturbance. It was dominated by Russian thistle and lambsquarter with crested wheatgrass as subdominant. If the area had not been seeded, beardless wheatgrass and Indian ricegrass took the place of crested wheatgrass.

Following eight years of succession, crested wheatgrass became dominant with Russian thistle as the subdominant species. Rabbitbrush seedlings had also invaded the area.

Fifteen years after disturbance the shrub-grass community had developed, with rabbitbrush as the dominant species accompanied by eriogonum. The perennial grass component was typified by Indian ricegrass and beardless wheatgrass with crested wheatgrass becoming unimportant. Cheatgrass became prominent at this stage in succession. A forb component composed of scorpion weed, wavyleaf thistle and mentzelia was conspicuous.

Seventeen years after disturbance, rabbitbrush and cheatgrass had not changed significantly while Indian ricegrass, beardless wheatgrass and crested wheatgrass had decreased considerably. Squirreltail and needle-and-thread grass had invaded but they made up only a small part of the composition. In addition, seven forbs collectively made up about one-fourth of the composition. The most important of these were wormwood and golden weed.

The <u>high elevation</u> ecosystems progressed through the same general stages during secondary succession following complete disturbance as indicated for the low elevation systems. However, the species vary slightly, especially in the shrub-grass stage. Rabbitbrush and cheatgrass were unimportant while big sagebrush, snowberry and serviceberry were the important shrubs. The number of forbs present at all stages was usually higher.

Early stages for the high elevation ecosystems were still dominated by Russian thistle with perennial grasses subdominant. Where seeded grasses did not become established, the native perennial grasses (beardless wheatgrass and Indian ricegrass) took their place.

Eight years after disturbance, succession had resulted in the shrub-grass community. In this case, big sagebrush was dominant with small amounts of rabbitbrush and snowberry. Crested wheatgrass comprised only 15 percent of the composition and was accompanied by beardless wheatgrass and Kentucky bluegrass. Cheatgrass was present but unimportant compared to the low elevation ecosystems. The forb component was quite conspicuous and included such species as knotweed, stickweed, dandelion and lupine.

Fifteen years after disturbance, the shrub-grass community was still present. However, crested wheatgrass had decreased and beardless wheatgrass had disappeared, while big sagebrush had increased and oak brush and serviceberry had become a part of the community. The forb component had not changed greatly.

After 17 years of succession, sagebrush had started to decrease while snowberry, oak and especially serviceberry were increasing. Only lupine and penstemon were present as important forbs. The grass component was now composed of small amounts of crested wheatgrass and Kentucky bluegrass.

The decrease in grasses after 15 to 17 years in both low and high elevation ecosystems has been attributed to heavy grazing pressure by domestic livestock rather than to the normal processes of secondary succession.

In the <u>bottomland sagebrush ecosystem</u> only a general successional pattern was evident. The initial vegetation was either an annual forb community or a grass community, depending on whether or not the area had been seeded. In this ecosystem, seeding of perennial grasses immediately resulted in a perennial grass community, instead of establishment of the perennial grasses over a few years as occurred in the low and high elevation ecosystems. If the area had not been seeded, an annual weed community of Russian thistle invaded the disturbed area.

Eight years of succession in the bottomland sagebrush ecosystem resulted in a shrub-grass community. The grass component was typified by cheatgrass and crested wheatgrass. As time since the disturbance increased, crested wheatgrass decreased until only two percent was present after 18 years. The cheatgrass component increased and reached a peak also at 18 years after disturbance. The forb understory apparently also changed during succession. During early stages, pepper grass was prominent. After 18 years, pepper grass had decreased to six percent. On the other hand, stickseed which made up one percent of the composition after eight years increased to 11 percent after 18 years. Golden corydalis and tumbling mustard, which were not present during early stages, had started to invade the community after 18 years. The species and amount of shrubs present did not appear to be the result of successional changes but rather the result of site and plants available to invade the area.

Succession Following Disturbance by Fire

The second year following burning in a low pinyon-juniper ecosystem, a western wheatgrass-scarlet globemallow community was present on the area. Small amounts of Russian thistle and knotweed were also present. After nine years of succession a big sagebrush-Indian ricegrass community developed and needle-and-thread grass and snakeweed had begun to invade.

A 13-year-old burn which had been reseeded also supported a sagebrush-grass community but the amount of sagebrush was considerably less than in the non-seeded area after nine years of succession. Crested wheatgrass was the most prominent grass species, while Indian ricegrass and needle-and-thread grass were present in amounts similar to the younger, non-seeded burn.

Ten years after burning in a high elevation pinyon-juniper ecosystem, the area was in a grass-annual forb stage of succession. Indian ricegrass and cheatgrass were the dominant grasses, while tumbling mustard was the prominent forb. Mountain mahogany and snakeweed were also present. This succession was in contrast to succession following complete disturbance in the same vegetative community. In the latter case, succession for the same period resulted in a sagebrush-grass community in which cheatgrass was unimportant.

Reseeding to crested wheatgrass may have suppressed the amount of Indian ricegrass and tumbling mustard. However, an increase in the number of grass and perennial forb species was noted in the seeded area.

Succession Following Chaining

Chaining in a low elevation pinyon-juniper community results in an increase in the perennial plants already present in the community. In addition, forbs invaded the most disturbed and open parts of the community.

Indian ricegrass and beardless wheatgrass respond most directly. Russian thistle and cheatgrass dominate the more-completely disturbed areas such as those where trees have been uprooted. Other species in the community increase more slowly; however, they all respond with increased vigor and height growth.

Ten to 15 years after chaining in the high elevation pinyon-juniper community, snowberry, big sagebrush and serviceberry dominate the successional stage. Pinyon and juniper begin to appear as a result of the growth of seedlings and young trees not destroyed at the time of chaining.

Indian ricegrass and Junegrass were the dominant grasses following ten years of succession, but these grasses decreased and were not present on the areas chained 15 years prior to this study. Beardless wheatgrass was present only on areas which had been subjected to succession for 13 to 15 years.

Other forbs and grasses typical of this ecosystem were present in the successional communities in small amounts but did not respond in any definite pattern.

Artificial Rehabilitation

As with natural succession, rehabilitation by artificial means is dependent upon climate and soil conditions and topography. Most areas receiving ten inches or more annual precipitation with moderate slope and a satisfactory plant growth medium can be successfully rehabilitated by presently-known techniques. These include saving the top soil to be redistributed over the replaced overburden to depths of at least four to six inches. The combination of top soil and subsoils should be at least 18 to 24 inches in depth to store moisture for plant growth.

In most cases, drilling the seed is preferred to broadcasting.. In all cases, the seed should be covered to a shallow depth with soil. If mulches are used in conjunction with seeding on the more harsh sites, the seed should be planted and covered with soil before the mulch is added. Intensity of seeding is important. Poorer sites generally require twice as much seed as favorable sites and broadcasting requires twice as much seed as drilling.

Selecting adapted species for the sites to be seeded may mean the difference between success or failure. In the Piceance Basin there is a choice of at least ten to 15 native species for each local area and perhaps three to four introduced species that would adapt to the various sites.

In many cases, fertilizers such as nitrogen and phosphorus may aid in plant establishment on disturbed areas. Where possible, supplemental water should be added to initiate plant establishment.

It may be necessary to control annual weed growth before planting or following seeding to enhance seedling establishment. This may best be accomplished by the use of appropriate pre- and post-emergence herbicides.

The final step in obtaining a satisfactory cover of vegetation after seeding is grazing management while the seedlings are becoming established. Young seedlings should not be grazed until they are firmly rooted. Fencing may be required to control grazing for three to six years following planting.

Vegetation community types with moderate potential for rehabilitation include those in the entire foothill zone of the Piceance-Yellow Creek Basin. Past history of seeding shows that satisfactory results can be accomplished if the proper methodology is used.

Vegetation community types that will be difficult to rehabilitate include those in the desert areas in lower portions of the valley basins. These areas receive low annual precipitation, may be alkaline, and may have poorly developed soil. Revegetation will not be accomplished by conventional artificial means. Therefore, natural succession can be implemented by adding water initially and planting native seed sources in terraces or basins.

Ecosystems with a high potential for rehabilitation include forests, grasslands and mixed mountain brush types which grow at higher altitudes where precipitation is favorable for plant growth.

EVALUATION OF MINING TECHNIQUES

Underground Mining

Room and Pillar

When contemplating the mining of oil shale by an underground method, it appears that the most viable approach would be the room and pillar technique or some modification thereof. This technique would yield an estimated 60 percent extraction of the Mahogany zone by mining rooms on the order of 50-60 feet high and 60 feet wide, leaving pillars with dimensions approximately 60 x 60 feet.

If spent shale is to be introduced underground as fill material, the room and pillar technique will probably be modified to a panel and pillar method in order that mined-out panels may be completely filled. With various modifications an effective extraction ratio of about 80 percent could probably be achieved without serious surface consequences because the fill would prevent large displacements within the mined-out sections or panels.

Block Caving

Block caving is a mining method in which large blocks of ore are removed and then the roof is allowed to cave due to the weight of the ore material above. This broken material is drawn from the bottom of the block. Additional caving upward is accomplished by drilling and blasting.

Not all types of deposits are amenable to block caving. The success of this method depends largely on whether the ore breaks readily into small fragments. This, in turn, depends upon the extent of "inherent fractures" within the cavity unit. So-called "weak ore," defined as easily-fragmented ore, is generally considered ideal for block caving operations. In the case of oil shale, additional fracturing for efficient block caving may be required. This could be accomplished by controlled blasting in the block area.

Because of the low mining cost associated with block caving, it is an attractive extraction method providing the deposit fits the method requirements. In general, it is safe to assume that some variation of block caving could be applied to mining oil shale.

Occidental Processing Method

The occidental processing method is essentially an underground mining technique combined with in situ retorting. With this approach, the thickness of the oil shale should be at least on the order of 60 feet. The room and pillar mining method is used to develop the deposit and establish the required collection rooms. Vertical four-inch diameter holes are drilled through the oil shale above. These holes are then loaded with 60 percent ammonium nitrate and blasted, creating a large chimney of broken or fractured oil shale material. Surface drill holes are then extended into this chimney and hot surface-produced gases convert the kerogen to oil which is collected in underground "neutralizing" rooms for purification. The final product is then pumped to the surface.

One of the primary advantages of this technique is that the extraction process is conducted underground. The only facility on surface would be a power plant. The oil shale mined conventionally as the rooms are developed could be sold to another company having a surface retorting facility.

Shafts and Adits

Access to sub-surface orebodies is usually attained through shafts or adits and should a mining property lend itself to either approach, the adit is generally the choice. Exploitation by way of adits offers lower cost of driving the opening, greater safety and ease of materials handling, better mine drainage, less surface plant needs, and the lowest possible exploitation cost.

Surface Mining

The U. S. Department of Interior determined that the area in Colorado most amenable to open pit mining of oil shale is a tract designated as Colorado C-a, owned by the United States. This 5,089-acre tract of oil shale is located in T1S, R99W, in Sections 32, 33 and 34, and in T2S, R99W, in Sections 3, 4, 5, 8, 9 and 10. The lands described are all within Rio Blanco County, Colorado.

The Mahogany zone in this tract is 50 feet thick, averaging 30 gallons of oil per ton, with 450 feet of 30 gallons per ton oil shale directly beneath the Mahogany zone. Overburden in the tract varies from 100 feet to 850 feet in thickness with an average of 450 feet.

Typical open pit mining does not lend itself to waste disposal by filling until the mining has been completed. However, it is believed that an open pit mining plan can be developed to dispose of the overburden waste in the open pit while advancing on the production of oil shale. Doing so would reduce the cost of disposing of waste overburden into box canyons and, furthermore, would disturb less of the existing environment. Much of the overburden in the early years of mining would have been used to fill box canyons and thus would leave space in the open pit for disposal of spent shale. Proper scheduling of filling the open pit would be necessary in order to have a layer of spent shale above the overburden waste which in turn would be covered by the original top soil for revegetation.

In Situ Processing

Perhaps the most attractive method, at least in theory, for producing shale oil is by *in situ* retorting. This process involves the extraction of oil from the shale in place by heating. This approach would eliminate the mining of oil shale, the problem of disposal of spent shale, and the possible contamination of surface or subsurface waters as a result of surface disposal of these materials. In addition, air pollution would be reduced or minimized when compared with that expected from surface retorting. It is envisioned that *in situ* processing would be most applicable to the thick, deep layers of oil shale occurring near the center of the Piceance Creek Basin.

Various techniques for supplying or creating heat have been tried or proposed including superheated steam, underground combustion, heated natural gas or carbon dioxide gas, hot solvents and combinations of the above. The principal technical problem is that most oil shale beds have practically no permeability and are rather poor conductors of heat. Two prerequisites for in situ retorting are: (1) the creation of sufficient surface area and fluid permeability with the rock mass to sustain combustion, and (2) to provide flow paths for oil, gas, and combustion products.

At present there are many factors associated with a nuclear fracturing which need special attention and study. These factors are: (1) ground motion, (2) containment of radioactivity released from the explosion, (3) size and shape of the chimneys, (4) size distribution of the broken rock, (5) the type and amount of radionuclides, (6) air pressure required to retort the shale, (7) the efficiency with which the shale could be retorted from the chimney, and (8) the impact on ground water quality. The lack of firm data precludes further analysis of this technique at present.

Another variation to in situ processing is a combination of underground mining and in situ retorting. Approximately 30 percent of the in-place shale would be mined by an appropriate underground method and transported to the surface for conventional retorting. The remainder would be fragmented, probably by large, well-placed conventional explosives, to fill the mined-out voids and thus prepare a strata amenable to subsequent in situ retorting by fire-flooding techniques. This technique has not been tested and should be considered only as conceptual.

Problems of Spent Shale

Spent shale refers to the solid residue left behind after retorting of oil shale. It is a complex waste product whose physical and chemical properties vary widely. Primary controlling factors are: (1) composition of the oil shale before retorting, (2) preparation of the shale for retorting,

(3) type of retorting process used and (4) the conditions encountered after retorting. Depending on the grade of shale being processed, the weight of spent shale is about 80-85 percent of that of the originally-mined oil shale. The volume of the spent shale, even after compacting, is at least 12 percent greater than its in-place volume. This is due to void spaces in the mass of crushed and retorted material which are not present in the shale prior to mining.

There are three alternatives available for the disposal of spent shale: (1) find consuming uses for it, (2) put it back in the mine, and (3) store it on the surface. If spent shale is to be introduced underground, compaction will be necessary for maximum volume replacement, to prevent mineral leaching by water percolating through the material, and to help control surface subsidence. Unfortunately, current technology for underground compaction of spent shale is not adequately advanced to accomplish all of these objectives. Even if technology were available, and the spent shale could be adequately and effectively drained of its water (from a slurry), it is expected that only 50 to 70 percent of the spent shale could be returned to the mine. This is because of its increased volume over the original _in situ_ volume. Therefore, it would seem necessary to permanently store at least a portion (about 40 percent). if not all, of the spent shale on the surface.

In open pit operations it is hoped that much of the spent shale can eventually be put back into the pits and revegetated. Replacement of spent shale can proceed when: (1) sufficient space becomes available in one portion of the pit which has reached final pit limits, or (2) when a later pit operation is ready to fill the void created by an earlier pitting operation in a multiple pit arrangement. However, as with underground mines, considerable volume removal has to precede any replacement; otherwise, spent shale disposal operations would interfere with mining.

Compaction will be used to control not only the erosion of spent shale by wind or water, but to eliminate the possibility of its liquification. Moistening and compacting spent shale as a part of the disposal procedure can materially expedite surface-cementation reactions, resulting in a nearly impervious surface which will prevent leaching of the soluable components.

Compaction will probably be effective in combating spent shale erosion during normal runoff; however, additional measures will have to be applied to cope with the summer flash floods common to this area. These steps are:

(1) Construction of a control reservoir upstream from the disposal pile.

(2) Installation of a conduit or other facility to transport water from the reservoir to a location downstream from the pile.

(3) Construction of a retaining dam and pond downstream from the pile to collect surface runoff from the pile and allow any sediments to settle out.

(4) Installation of pumping facilities to remove the collected water from the settling pond and deliver it to the process area for use in moistening the spent shale.

PHYSICAL AND CHEMICAL CHARACTERISTICS OF OVERBURDEN, SPOILS AND SOILS

Building sites, drill sites, roads, mine shafts and very large open pit mines will all in some manner disturb the surface soil and rock layers. Rehabilitation after surface disturbance requires knowledge of the soils rock characteristics that make up the overburden, and in particular, those physical and chemical properties known to be critical for plant growth. Among the physical characteristics of interest are particle size distribution after ripping and/or blasting and regrading operations, and the rate of breakdown of coarse fragments into soil-sized particles. If the disturbed overburden (spoil) is to support a plant cover under the climatic conditions found in the area, it must contain sufficient soil-size materials to hold water. On the other hand, it should not be so fine textured or dispersed that runoff will be excessive. Chemically, the items of most interest in the soils and various strata of the Green River overburden are soluble salts, pH, amount of nitrogen and phosphorus available to plants, and possibly toxic elements.

If these physical and chemical characteristics of the existing soils, soil-like materials, and rock spoils are known, it may be possible to plan the mining and spoil disposal operations so that materials best suited for plant growth are left exposed after regrading. And conversely, those spoils unsuitable for plant growth or detrimental to runoff water quality can be buried under spoils more suitable for plant growth or covered with existing soil materials.

Overburden

Stratigraphy and Definition of Overburden

All of the oil shale and overburden in the Piceance Basin is in the Green River formation. Of interest in this study is the Parachute Creek member above the oil-rich Mahogany zone and the overlying Evacuation Creek member of the Green River formation. Overburden is defined as being any rock lying above the upper limit of commercial oil shale, thus includes most of the rock above the Mahogany zone.

Thickness and Extent

The overburden covers most of the surface of the Piceance Basin except in the valley bottoms on the basin's southern perimeter. Its thickness varies considerably because the thickness depends on the amount of Evacuation Creek member remaining after erosion, and on how much of the material between the base of the Evacuation Creek member and the Mahogany zone is commercial oil shale. The overburden thins toward the basin's perimeters, with the thinnest areas along the west-central border, and the thickest in the east-central part of the area.

Rock Type and Mineralogy

The limited stratigraphic data collected for this study indicate that the overburden consists of 36 percent to 67 percent sandstone, 7 percent to 22 percent siltstone, 7 percent to 36 percent limestone (marl) and two percent to 27 percent shale. The shale is locally subeconomic oil shale. The sandstones and siltstones are composed of quartz, feldspar and rock fragments cemented by calcite. The majority of the rock fragments are volcanic in origin. The limestones are 90 percent to 95 percent calcium or calcium-magnesium carbonate which contains five percent to ten percent quartz, feldspar, and clay. The shales consist of 50 percent to 60 percent clay minerals, ten percent to 46 percent calcite or dolmite and one percent to 30 percent quartz, feldspar and micas.

Physical Properties

The physical property studied was the development of fine particles in fresh broken, in crushed and in naturally-weathered overburden rocks. Too many fine particles will produce a highly-erodible material, and not enough fines produces a material that will not hold adequate water for plant growth. Fresh broken samples of all overburden rocks tended to be coarse-grained with 80 percent to 95 percent between 4 and 256 mm, and only one percent to five percent less than 1 mm. Crushing reduced the grain size, producing ten percent to 20 percent more fines than fresh samples. These fines produced by crushing are smaller than the minimum closure of the crusher jaws, reflecting the friability of the rocks. Natural weathering produced 20 percent to 50 percent fines less than 1 mm in many rock types. Rates and amounts of weathering on fresh overburden is unknown but is now being researched.

Recommendations

Data presented in this report on compositions and physical properties of overburden rocks are based on measurement and sampling of three stratigraphic sections. Because of the high degree of variation of both composition and physical properties across the basin, it is recommended that eight to ten more stratigraphic sections be measured, sampled and analyzed. In addition, it is recommended that chemical and x-ray analysis of composition be added to the methods used here.

Rates and amount of weathering of overburden rocks may be very important in the production of fine particles and thus in the rehabilitation of disturbed overburden. It is recommended that detailed studies of these rates be conducted on overburden rocks from different elevations and areas in the basin.

Disturbed Overburden as a Medium for Plant Growth

A very preliminary attempt to evaluate disturbed geological materials in the lower Evacuation Creek member as plant growth media was made by sampling materials that had been exposed and graded in drill site preparation and then regraded for site rehabilitation. The samples were taken in

September, 1972, on sites that had been disturbed and regraded a few days or weeks before sampling. Four different sites were sampled. Three samples (samples 1 - 3, Table 2) were on the oil shale lease site C-a, and one (two different geological materials, samples 4 and 5, Table 2) were from near the mouth of Piceance Creek.

The analyses indicate that one problem in vegetation establishment and maintenance on these spoils may relate to the small amount of soil-size material and consequent low water-holding capacity of the spoils.

The soluble salt concentrations would present slight to severe problems in seed germination and plant establishment.

Meaningful soil tests for plant-available nitrogen (N) in geological materials are not available; however, plant-available N is usually very deficient on subsoil and spoil material. If these spoils are used as plant growth media, maintenance application of N will probably be required over a period of years.

Plant-available phosphorus was very low on four of the five samples. Phosphorus fertilization would appear to be feasible on these spoils and the effect should be long lasting.

The pH of the spoils is that expected in highly calcareous materials and should not be a limiting factor in growth of plant species adapted to the area. The pH of 8.8 in Sample 4 may indicate a material high in exchangeable sodium which suggests soil dispersion and resulting in slow water infiltration.

Much of the plant establishment information in Chapter 3 of this report will also be applicable to spoils.

Table 2. Some particle size and chemical characteristics of disturbed geological materials from the lower portion of the Evacuation Creek member of the Green River Formation.

Sample No.	1	2	3	4	5
Material	silty calcareous shale	alluvial fan	calcareous mudstone	sandstone	limestone
Particle Size					
>3" diameter (%)	4	0	3	7	14
1/2 - 3" (%)	34	4	32	49	54
2 mm - 1/2" (%)	33	28	36	23	19
<2 mm (%)	29	68	29	21	13
The following analyses are on the soil-size (<2mm) material:					
Particle size (hydrometer)					
Sand .05 - 2 mm (%)	47	24	12	24	32
Silt .002 - .05 mm(%)	19	33	33	36	32
Clay <.002 mm (%)	34	43	55	40	36
Texture	sandy clay loam	clay	clay	clay loam	sandy clay loam
pH[1]	8.4	7.9	8.0	8.8	8.5
Conductivity mmhos/cm[2]	4.2	9.0	4.0	2.2	1.0
$CaCO_3$ equivalent (%)	40	18	37	21	46
P ppm[3]	12	3.5	1.3	.5	2.0
K ppm[4]	82	110	68	68	55

1 Determined on 2-1 distilled water - spoil ratio. 2 Saturation extract. 3 By sodium bicarbonate extraction. 4 Soluble plus exchangeable determined on a 1N ammonium acetate extract.

Recommendations

Intensive overburden sampling and evaluation is needed if disturbed geological material (spoil) is to be used as media for plant growth. Particle size distribution in the spoil will be of primary importance. Soluble salt content will also be important. Plant-available nitrogen and phosphorus will be very deficient in the spoils and good management with N fertilization will be required.

An alternative would be to cover the spoil with soil. If such an approach were used, a soil survey should be made before disturbance to determine the extent of soil suitable for covering spoil and also plan for the soil handling.

Soils of the Oil Shale Area

The soils of the oil shale area are highly variable in many important characteristics: depth, texture, structure, stoniness, rockiness, chemical properties, and temperature and moisture regime. Variability in these characteristics implies a wide range of drainage, infiltration, permeability, erodibility, fertility, water-holding capacity and other soil conditions important to the revegetation of disturbed lands.

Following is a summary of the adequacy of existing soils information for making interpretations concerning the revegetation and stabilization of disturbed lands in the oil shale area of Colorado.

Available Mapped Chemical and Physical Soils Data

Detailed soil survey information does not exist. Some chemical and physical soil characterization data were obtained during the course of this study and some data are available from previous studies.

A general soils map, completed by the Soil Conservation Service, USDA, at a scale of 1:250,000 is available for the entire area. The general soil map and accompanying interpretive information gives a broad overview of the soils in the oil shale area. This information was based on limited field and laboratory investigations. Thus, caution must be used in making interpretations relative to the development, management and behavior of the soils found in the area.

Classification of Soils

Due to the limited amount of soil survey data available, the soils of the study area have been classified only into broad categories. From the general information, however, some relationships can be discussed which are important to consider in the rehabilitation of disturbed lands.

Existing soil classification information indicates that chemical, physical and biological weathering processes, and subsequently, soil formation take place at a rather slow rate in most environments of the area. This factor is important when considering the type of soil or soil-like materials to be used as a plant growth medium on disturbed areas. Every effort should be made to use materials having adequate water-holding capacity and a minimum of adverse chemical properties (e.g., soluble salts).

Existing soil classification information identified potential sources of topsoil or soil-like materials which would be suitable as a plant growth medium. However, the nature and extent of these materials cannot be determined accurately from existing information.

Existing information relating to soil moisture regimes indicates that there are some areas where leaching of soluble salts could occur. In other areas the soil moisture regimes indicate that little or no leaching would occur but rather salt accumulation would be a problem.

In addition, the moisture regimes of the soils found in the area vary widely with respect to the periods of the year in which soil moisture is available for plant growth.

Information derived from the definition of soil classes indicates that many of the soils, if disturbed, would be highly susceptible to both wind and water erosion.

Recommendations

This study indicates that existing soils data are not adequate for defining the extent of different soils and their chemical and physical properties in the detail needed for making reliable interpretations. The information available indicates that there are opportunities as well as some serious constraints posed by soils with respect to the rehabilitation of disturbed lands. Major areas of concern are: wind and water erosion, soil moisture relationships, fertility levels, sources of topsoil or soil-like materials suited as a medium for plant growth, potential leaching and/or accumulation of soluble salts and engineering stability.

Detailed soil surveys and research are needed to: 1) identify and characterize potential sources of topsoil or soil-like materials for use in covering spent shale and coarse-textured spoils; 2) develop recommendations for conversation practices needed to overcome or minimize potential erosion problems; 3) better define the soil moisture regimes that presently exist so that reliable recommendations can be made concerning available soil moisture for plant growth and for evaluating leaching and/or accumulation of salts; 4) determine the fertility and chemical nature of the soils; and 5) provide information for evaluating soil behavior for other uses, such as roads, building sites and pipeline routes.

CHARACTERISTICS OF SPENT SHALE WHICH INFLUENCE WATER QUALITY, SEDIMENTATION AND PLANT GROWTH

Development of an oil shale industry in the Piceance Basin will require the disposal and stabilization of spent shale and overburden spoils at a scale unprecedented in the history of mining. A projected 250,000 barrel-per-day industry will produce more than 110 million tons or about 86 million cubic yards of spent shale per year. Utilizing the proposed disposal sites, approximately 5500 surface acres of spent shale material will require stabilization during a 20-year period.

The magnitude of the spent shale disposal problem indicates that characteristics of the spent shale material must be thoroughly evaluated to permit safe disposal pile design, efficient and permanent stabilization, and to minimize environmental problems. The objective of this chapter is to identify the physical, chemical, and hydrological characteristics of spent shale materials derived from current retorting processes. Emphasis is placed on identifying potential problems in stabilizing spent shale piles, including potential leaching and erosion, and on a consideration of spent shale as a plant growth medium.

Physical, Chemical and Hydrological Characteristics of Spent Shale

The physical, chemical and hydrological characteristics of spent shales vary according to the mining and retorting methods used. In this study spent shales from three existing retort processes are examined. These include the TOSCO II process, the U.S. Bureau of Mines gas combustion process, and the Union Oil Company underfeed retorting process.

In the TOSCO II process, finely-crushed oil shale is heated to approximately 900°F so that the organic matter decomposes without burning. Spent shales which result from this process consist of a fine, dry black powder. The material, as it comes from the retort, has a bulk density of about 70 lbs/ft^3, and consists of predominately silt-sized particles. In the studies cited, no particles greater than 8mm were found, with 85 percent or more of all particles less than 2mm in diameter, and 60 to 68 percent of all particles in the .05 to .002 mm (silt) size range. The density of the particles was reported to be 2.49 g/cc and the non-compacted material had a porosity of about 47 percent and a field capacity of about 20 percent by weight water.

The U.S. Bureau of Mines process produces a coarser-textured spent shale with about 34 percent of all particles greater than 8mm and about 40 percent in the soil-size range (<2mm). Particle densities are reported to be 2.46 g/cc, bulk densities 60 to 80 lbs/ft^3, and porosity 41 percent. Field capacity of the less than 2mm material was reported as 20 percent by weight water.

Spent shale produced by the Union Oil Company underfeed retort process has not been studied as intensively as the spent shales from the other two processes. This process heats the shale to approximately 2000°F, which burns off the residual carbon and causes a fusion of the spent shale particles. The result is a clinker type of spent shale with particle densities reported as 2.71 g/cc, bulk densities from 70 to over 100 lbs/ft^3, and porosity at 33 percent. Most of the material is smaller than ten inches.

The hydrologic characteristics of spent shale also vary with the retorting process. Studies of water intake rates (infiltration rates) on spent shale piles suggest that the intake varies according to the condition of the surface. Meiman (1973) reported one-hour infiltration rates for a variety of spent shale types and conditions. One-hour infiltration for an old Bureau of Mines pile averaged 1.2-1.6 inches/hour. TOSCO II spent shale piles had average intake rates of 0.8-1.0 inches/hour when the surface soil was moist, but approached zero when the surface had been allowed to dry and become salty.

Low infiltration rates may be related to the natural resistance of the spent shales to wetting. TOSCO II spent shales have been reported as being highly water repellant. However, this problem has apparently been solved by pre-wetting the spent shales as they come from the plant. U.S. Bureau of Mines and Union Oil Company spent shales have not been reported as non-wettable.

Permeabilities of spent shale piles are about 13 mm/hr for U.S. Bureau of Mines spent shales and 1.0 to 1.5 mm/hr for TOSCO II spent shales. These values were reported for non-compacted spent shales which had not been previously wetted. Much work remains to be done on permeabilities of compacted spent shales.

Chemical analysis of spent shales show them to be highly saline and highly alkaline. There is a potential for high concentrations of Na, Ca, Mg, and SO_4 to be leached from spent shale piles. Leaching studies of spent shales show high concentrations of salts from all three types of spent shales. From the leaching studies reported, it appears that salts can be readily leached from the spent shales. Present data suggest that ten inches of leach water through a three-foot layer of spent shale will reduce the electrical conductivity of that leachate to below 4.0 mmho/cm. However, four feet of leach water or more, may be required to permanently reduce the salt content to acceptable levels for plant establishment and growth.

Spent Shale Disposal

The development of an oil shale industry will depend upon the development of satisfactory methods for stabilizing the spent shale disposal areas that will minimize both present and future environmental degradation. Disposal and stabilization must be accomplished with three primary objectives in mind: 1) design of the pile and stabilization of the surface to protect against wind or water erosion; 2) location and/or design of the pile to prevent leaching and chemical pollution of surface and ground waters; and 3) design of the pile to prevent mechanical failure and subsequent erosion of the sloping face. This suggests that spent shale piles should be located in areas where the natural terrain offers some degree of protection and natural containment with respect to climatic and hydrologic processes.

The most probable method of spent shale disposal will be to pile the material in canyons or other natural depressions in the terrain. This has a number of advantages. It permits a deep pile (low ratio of surface area to volume) with some protection from the elements. The area of sloping face to be stabilized is comparatively small and the bulk of the pile is hidden from public view. The primary disadvantage is that the pile lies across the natural drainage way and will require special measures to route natural flows either beneath or around the piles. Stabilization problems include: 1) controlling runoff onto and over the pile so as to prevent erosion; 2) preventing water from moving into or through the pile; and 3) stabilizing the face and top of the pile. Since it will be many years before the top of the pile will be ready for stabilizing, temporary erosion control measures must be considered.

These will include debris basins or other retaining structures downstream from the pile, and temporary drainage controls above and on top of the pile.

Compacting the surface of the pile as it is formed will reduce the intake of water into the pile. Bulk densities of 90 to 100 lbs/ft^3 can be achieved by wetting and mechanically compacting the spent shale as it is deposited in the disposal area. However, the formation of an impermeable surface means that surplus water from rainstorms or melting snowpacks must be drained from the surface without eroding or leaching salts from the surface.

A problem to be considered is the effect of snow accumulation on the piles. The proposed disposal areas are in the canyons and natural depressions which also form natural snow accumulation areas, especially at the higher elevations. The accumulation of deep snowpacks on the spent shale piles could create a source of water for runoff and infiltration which could require additional control measures.

Stabilizing the face of the pile will also require special measures to control runoff and infiltration. The most critical considerations are the slope of the face (25 percent appears to be reasonable), provisions for control of runoff such as cross drains or terraces, prevention of runoff from the top of the pile, and stabilization of the surface by vegetation or other means.

Spent Shale as a Medium for Plant Growth

The ultimate stabilization of the disposal sites will require the permanent stabilization of the face and top of the pile through vegetative or other means. Vegetation is the most logical, aesthetically-acceptable and economical method.

Spent shales are initally too salty for plant establishment and growth. Information from literature and preliminary observations indicate that about four feet of leach water may be required to reduce the salt to levels acceptable for revegetation. The leaching process can be accomplished by a properly-designed sprinkler system. Major problems posed by the leaching treatment are disposition of the leach water and resalinization of the leached zone.

Plant-available nitrogen (N) is extremely deficient in spent shales. Application of 60 to 100 pounds of N per acre will often give good growth response on such N-deficient materials. However, the vegetative cover will decrease if legumes are not a major component of the stand. Thus, maintenance application of N will be required over a period of time. Plant-available phosphorous (P) is also extremely deficient in spent shales. P fertilization appears feasible and appears to pose less of a maintenance problem than does N.

Freshly-retorted spent shales will vary in pH with the retorting temperature and possibly with the amount of sodium carbonate minerals present. Extremely high pH spent shales (pH 10-12) may present both chemical and physical problems due to cementation. Possible dispersion of leached spent shale by high concentrations of exchangeable sodium needs study as does possible boron toxicity to certain plant species.

Particle size differences among spent shales produced by the various retorting processes will have a profound effect on moisture relationships, species adaptability and revegetation procedures. Infiltration rates on fine-textured spent shales could be critical if reduced by compaction. The dark color and resulting high surface temperature is another factor to consider when evaluating spent shales for plant growth.

Covering spent shale with soil or geological material would eliminate or ameliorate some of the foregoing problems.

Recommendations

This review and summary of known characteristics of spent shale suggests many questions which require additional research and consideration by the organizations responsible for the rehabilitation of spent shale piles. One of the most obvious deficiencies is the amount of information on spent shale materials. All of the data and conclusions presented in this report are based on spent shales from pilot project plants which may not be representative of spent shales from commercial scale plants. As a result, planned restoration measures may require modification when the proposed plants become active. A number of other recommendations may be made:

1. Detailed water balances should be calculated for the specific disposal areas so as to determine the probability of leaching and pollution at each site. This would require the installation of good quality weather stations and collection and analysis of data during the development phases of the various proposed plants.
2. A thorough analysis of erosion potentials and erosion control measures should be made at each disposal site prior to actual disposal. This should include recommendations on techniques for compaction, drainage and surface erosion control.
3. The use of soil cover on the spent shales should be tested and evaluated with respect to leaching requirements, water balance calculations, plant establishment and potential erosion.
4. The use of coarse-textured soil or rock on the face of the spent

shale pile should be considered and tested with respect to plant water availability, erosion potential, leaching potential and other stability considerations.

WATER REQUIREMENTS FOR STABILIZING AND VEGETATING SPENT SHALE IN THE PICEANCE BASIN

One of the most important factors in the development and ultimate size of an oil shale industry for the Piceance Basin of Colorado is the availability of water. This report attempts to provide a realistic estimate of irrigation water requirements for revegetating disturbed areas and surface waste disposal areas for spent shale and overburden. Irrigation requirements are based on evapotranspiration estimates calculated with a modification of the Jensen-Haise method.

The modified Jensen-Haise method for estimating evapotranspiration provides monthly water use estimates for both the winter (moisture accumulation period) and the growing season. The methodology also was adapted to provide evapotranspiration estimates for specific vegetation types on different slopes and aspects, and for areas having different temperatures. The complete report provides relatively simple equations that can be used to estimate evapotranspiration (or irrigation water requirements) for specific vegetation types growing on 0-50 percent slopes and eight aspects.

The major disturbances from an oil shale industry will be the result of: 1) surface disposal of spent shale and overburden; 2) storage areas for mined shale; 3) land areas for retorting plants and mine facilities; 4) road and utility rights-of-way and borrow areas; 5) floodwater-retarding structures (or debris basins and sediment traps) to protect plants, disposal areas, or downstream floodplains; and 6) urban areas associated with the oil shale industry population increase.

Disposing of at least 52,700 tons per calendar day (tons/cd) of spent shale and other solid waste products for a 50,000 barrel-per-calendar-day (bbl/cd) commercial scale oil shale retorting plant poses a major problem. For an oil shale industry of 1,000,000 bbl/cd, the spent shale and other waste product disposal problem could ultimately exceed one million tons per calendar day, and the area requiring revegetation could approach one thousand acres per year.

The extent of overburden disposal areas requiring revegetation is directly related to the extent of surface mining. It is estimated that a 100,000-bbl/cd oil shale industry utilizing surface mining would require off-site disposal of some 256 million cubic yards of overburden, and that an operation of this size would require the revegetation of approximately 50 acres of overburden per year.

Water Required for Revegetation

Leaching Requirement - Spent Shale

Spent shale can be used as a plant growth medium if the salt content in the root zone is reduced to a tolerable level. Leaching appears to be the only feasible method of reducing the salt content. The net leaching requirement for spent shale is estimated to be about 48 inches of irrigation water. It was assumed that leaching would be accomplished with sprinkler irrigation using very low application rates (about 0.10 inches/hour), and that irrigation efficiency would be about 80 percent. Therefore, the gross irrigation requirement for leaching would be 60 inches, or 5.0 feet, of irrigation water per surface acre of the spent shale disposal area being revegetated. However, there are a small number of unsolved problems related to leaching spent shales for permanent revegetation.

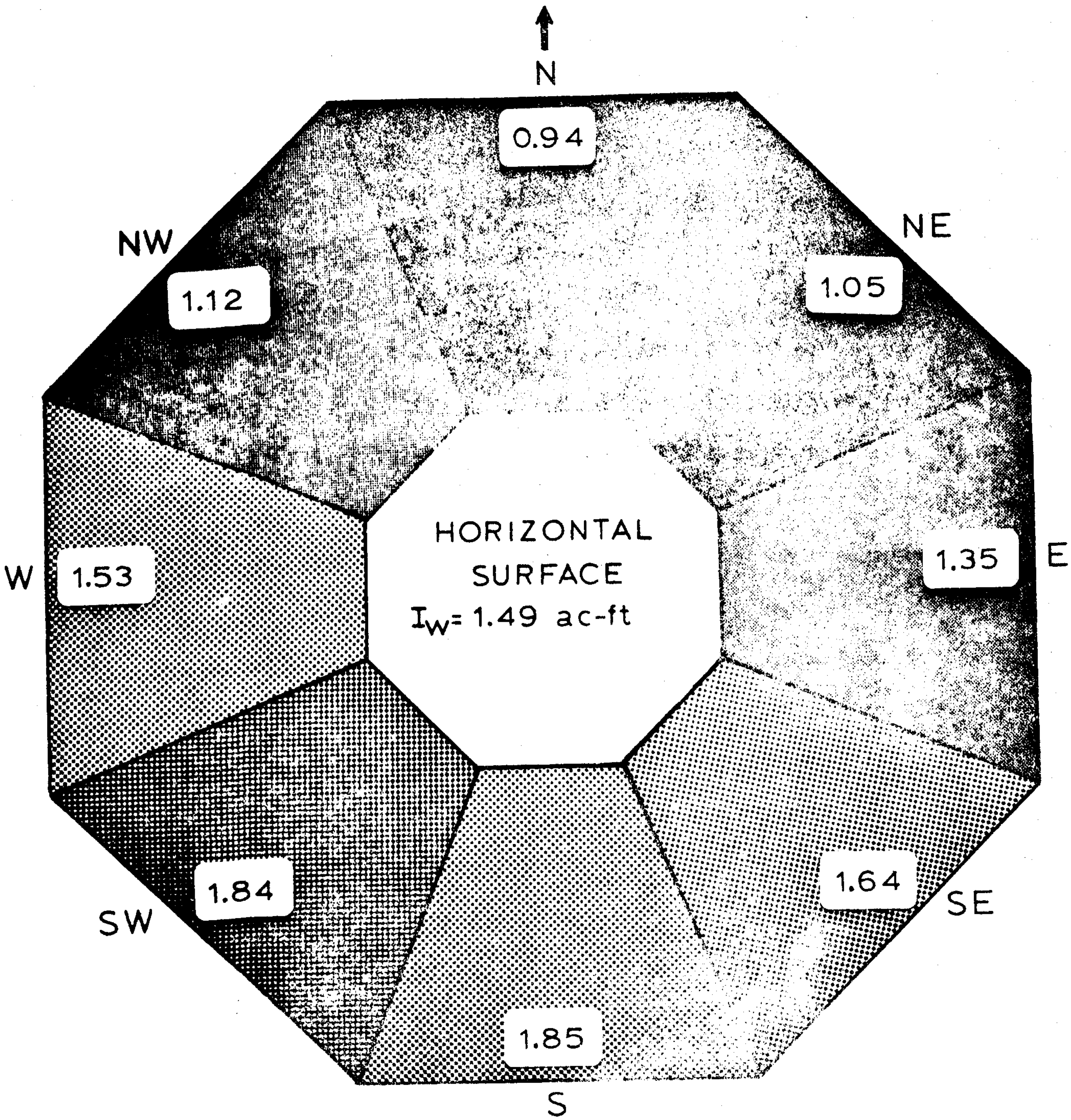


Figure 5. Estimated irrigation water required (Acre-feet) for full season irrigation on the horizontal surface and 25% slope facings of revegetation areas at 7,000 ft.

Irrigation Requirement

Monthly evapotranspiration estimates were developed for spring-planted vegetation, and full season (one-year) use, for a horizontal surface at elevation zones from 5,000 to 9,000 feet using the modified Jensen-Haise method. Net irrigation requirements were estimated as evapotranspiration minus effective precipitation. The rooting zone for spring-planted revegetation areas was assumed to be 18 inches with 2.35 inches of available water-holding capacity, and the full season use was based on a 24-inch root zone with 3.16 inches of available water-holding capacity. Irrigation efficiency was assumed to be 75 percent.

Growing season evapotranspiration is lower for spring-planted revegetation areas, but because of lower effective precipitation during germination and plant establishment periods, the net irrigation requirement is essentially the same as for the full season.

Horizontal surface gross irrigation water requirements per acre for revegetation may be estimated as follows:

Spring-planted $I_{wsp} = (56.53 - 5.93E_1) / 10$

Full season $I_{wf} = (57.44 - 6.08E_1) / 10$

Two growing seasons $I_w = (113.97 - 12.01E_1) / 10$

where

I_w = gross irrigation water requirement per acre,

E_1 = elevation of site in thousand feet.

To illustrate the possible variations in gross irrigation water requirements, Figure 5 shows the net effect of 25 percent slope facings at 7,000 feet elevation. Table 3 shows the effect of elevation changes on gross irrigation water requirements.

Table 3. Estimated irrigation water required (acre-feet) for full season irrigation of ten-acre revegetation areas on a horizontal surface.

Month	Elevation zone 5,000 Acre-feet	6,000 Acre-feet	7,000 Acre-feet	8,000 Acre-feet	9,000 Acre-feet
April	.80				
May	4.66	3.03	1.08		
June	6.58	5.56	4.52	3.50	1.46
July	6.80	5.83	4.88	3.92	1.26
August	3.66	2.83	2.01	1.19	
September	2.17	1.51	2.39	.19	
October	2.37	2.20			
Total	27.04	20.96	14.88	8.80	2.72

Note: Per-acre irrigation requirements are obtained by dividing by 10.

Heat storage in large volumes of spent shale is unknown. It is reasonable to expect that snow will not accumulate on the surface of the disposal piles for a number of years. The normal growing season for any vegetation, thus, will be longer than in native soils. This combination of longer growing season and higher soil temperatures could increase total water requirements for the spent shale disposal areas. The report provides equations for estimating water requirements for the higher temperatures.

Water Requirements for a Hypothetical 250,000 Barrel-Per-Day Oil Shale Industry

Because it is difficult to present water requirements in the abstract, the 20-year and annual water requirements for a 250,000-bbl/cd oil shale industry were estimated. The specific oil shale industry was estimated to include two 50,000-bblcd plants on private land, a 100,000-bbl/cd unit utilizing surface mining at Federal Leasing Site C-a, and a 50,000-bbl/cd unit utilizing surface mining at Federal Leasing Site C-b. The mining and waste disposal volumes, land requirements and total water required were estimated for a 20-year project life of the 250,000-bbl/cd hypothetical oil shale industry.

The surface area requiring revegetation was estimated by evaluating the storage capacity of several canyons. For the two private land developments, Plant A was assumed to use surface disposal for 50 percent of the spent shale, and Plant B was assumed to dispose of 100 percent of the spent shale and other solid waste products in an intermediate size canyon (300,000 acre-ft. capacity). Federal leasing sites were evaluated from information in the USDI

(1973) Final Environmental Statement. Leasing Site C-a was evaluated on the basis of surface disposal for 80 percent of the spent shale and about 74 percent of the overburden. Federal Leasing Site C-b was evaluated on the basis of surface disposal for the first three years of production, then surface disposal of 40 percent of the spent shale for the rest of the project life.

Table 4 provides an estimate of the total water requirements for revegetation of surface spent shale and overburden disposal areas for 20-year and average annual periods. This evaluation is based on leaching, spring planting and full irrigation for two seasons. The total revegetation water requirements for a 250,000-bbl/cd industry amount to about 40,400 acre-feet for a 20-year operation, or an average of 2,020 acre-feet per year. The total 20-year water requirement for a 250,000-bbl/cd industry is estimated at about 628,570 acre-feet, so revegetation accounts for about 6.4 percent of the total water requirements.

Conclusions and Recommendations

If spent shale is to be used as a plant growth medium, irrigation will be needed to leach out salt and establish vegetation. Irrigation will often be desirable to rapidly establish vegetation on soils and geological materials disturbed by oil shale development, especially at the lower elevations.

Specific conclusions from the study are:

1. Approximately 60 inches of leaching water will be required, based on a net requirement of 48 inches leaching water and an 80 percent irrigation efficiency. Less may be required for soil-covered disposal areas.
2. With normal precipitation, total irrigation requirements are essentially equal for spring-planted and full season irrigation at any

Table 4-. Estimated water requirements for revegetation of surface spent shale disposal areas by leaching, spring planting and full irrigation for two seasons.

Revegetation site	Elevation zone	Revegetation water requirement Ac-ft/acre	Estimated 20-year revegetation acres	Water requirements Acre-feet Average Annual	Water requirements Acre-feet Total 20-years
Private land:					
Plant A					
Spent shale					
Leaching requirement		5.00	660	165	3,300
Irr. for revegetation					
Top surface	7,900	1.91	550	53	1,050
Sloping face	7,600	2.27	110	12	250
Subtotal		1.97	660	65	1,300
Total plant A		6.97	660	230	4,600
Plant B					
Spent shale					
Leaching requirement		5.00	950	238	4,750
Irr. for revegetation					
Top surface	7,000	2.99	820	123	2,452
Sloping face	6,500	3.59	130	23	467
Subtotal		3.08	950	146	2,919
Total plant B		8.08	950	384	7,669
TOTAL PRIVATE LAND		7.63	1,610	614	12,269
Federal land:					
Tract C-a					
Spent shale					
Leaching requirement		5.00	2,200	550	11,000
Irr. for revegetation					
Top surface	6,200	3.95	1,700	336	6,716
Sloping face	6,100	4.07	500	101	2,035
Subtotal		3.98	2,200	437	8,751
Overburden					
Irr. for revegetation	7,500	2.39	980	117	2,342
Total tract C-a		6.95	3,180	1,104	22,093
Tract C-b					
Spent shale					
Leaching requirement		5.00	740	185	3,700
Irr. for revegetation					
Top surface	6,900	3.11	600	93	1,866
Sloping face	6,700	3.35	140	24	469
Subtotal		3.16	740	117	2,335
Total tract C-b		8.16	740	302	6,035
TOTAL FEDERAL LAND		7.18	3,920	1,406	28,128
Total for 250,000 bbl/day industry		7.31	5,530	2,020	40,397

elevation zone. The gross irrigation requirement ranges from about 32.4 inches at the 5,000-foot elevation zone to 3.2 inches at the 9,000-foot elevation zone, with a decrease of 7.3 inches for each 1,000-foot increase in elevation. Specific water requirements will depend on the amount and type of precipitation received, elevation, slope, aspect and heat in the spent shale pile.

3. Of the estimated water required for a 250,000 barrel-per-calendar-day oil shale industry (31,428 acre-ft./year), a small fraction (6.4 percent or 2020 acre-ft.) is required in the revegetation of surface spent shale disposal areas.

Specific recommendations from the study are:

1. Design of spent shale disposal areas should concentrate on water control to prevent erosion and provide for the maximum use of available water by evapotranspiration.
2. The species mix for revegetation should include grasses, forbs, shrubs and tree species to provide more complete cover, and through variations in rooting depths, more complete use of available water supplies.
3. In the relatively "harsh" environment of the Piceance Basin, it will be difficult to maintain a desirable vegetative cover on the spent shale piles with natural precipitation. Therefore, it is recommended that revegetation plans call for the exclusion of all livestock and careful wildlife management.

Research Needs

1. Specific energy budget evaluations will be needed to determine long-term heat dissipation from spent shale piles, effect on

air temperatures above the disposal piles and their effect on water requirements.

2. If spent shale is to be used as a plant growth medium, additional research will be required to determine minimum water requirements and most efficient leaching methods.
3. An unanswered question in the use of irrigation to establish adapted species on critical sites is how long should irrigation continue. Research on particularly harsh sites should be conducted to determine the desirability of maintaining some supplemental irrigation capacity for maintaining a minimum cover during drought periods.