Rehabilitation Potential for the Henry Mountain Coal Field

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ENERGY MINERAL REHABILITATION
INVENTORY AND ANALYSIS

HENRY MOUNTAIN COAL FIELD

Garfield County, Utah

Prepared by
Utah State University
and
Utah State University Foundation
Logan, Utah

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This report notes and summarizes known baseline information relative to the coal deposits in the Henry Mountain Resource area in South Central Utah. Findings from chemical and biological analyses of eight geologic cores obtained from the overburden are correlated with field plantings on geologic outcrops and representative soils identified by a soil conservation service soil survey. Potential for rehabilitation is discussed and recommended procedures are presented.

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FOREWORD

This report was prepared by staff members of Utah State University working as consultants to Utah State University Foundation. The professional team consisted of the following:

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The purpose of this report was to assemble and summarize known baseline information relative to the Henry Mountain resource area and to present findings and recommendations from specific studies on suitability of geologic overburden and soils to support a rehabilitation program should the coal resource be developed.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. SUMMARY

I. SUMMARY

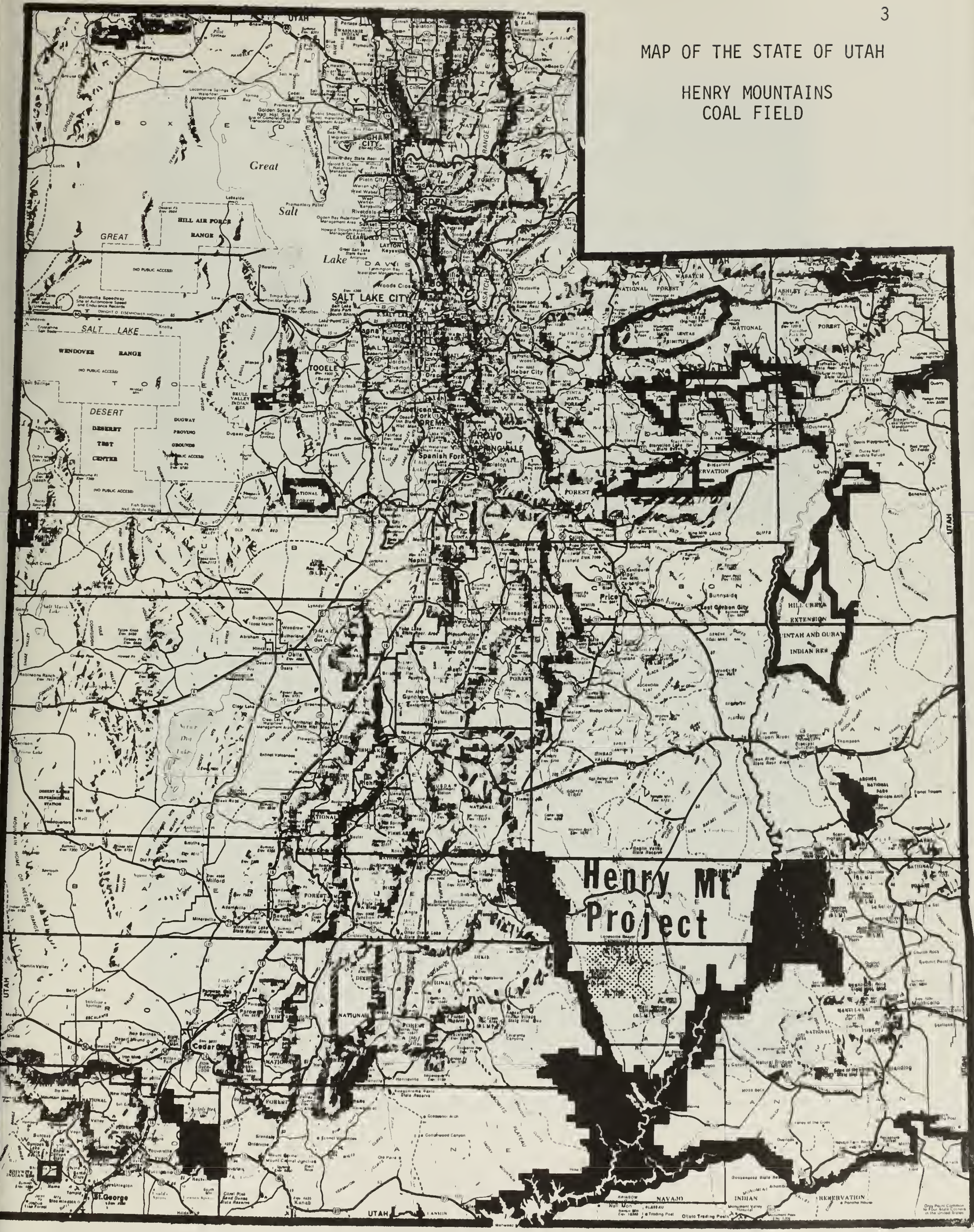
A. Introduction

This Energy and Mineral Rehabilitation Inventory Analysis (EMRIA) of the Henry Mountain Coal Field is an assembly and summary of much of the known baseline information about the resource area occupied by the coal field. Furthermore, it presents findings of specific studies on the suitability of the overburden and soils to support a rehabilitation program should the coal resource be developed. A limited study area in Garfield County, Utah (Figure 1) consisting of sections 17, 18, 19, 20 and 21 (T 31 S R 9 E) plus section 22 and 23 (T 31 S R 8 E) was assigned for detailed study. However, a more general area of study includes Wildcat Mesa, Pete Steele Bench and adjacent areas (Figures 2, 3).

B. Local Information

The general area in which the Henry Mountain Coal Field is located is one of the more remote and undeveloped regions of the United States. Until 1962 Highway 24 was not paved from Capitol Reef to Hanksville. The study site is accessible only by a seldom-graded dirt road extending 25 miles south from Highway 24. The nearest town is Hanksville with a population of 181 in 1970. Other communities in the region are also small with limited economic activity. Agriculture and recreational activities form the basis for employment.

Potential for development of recreation industries is great and is based on the outstanding scenic qualities of the region, specifically recognized by the establishment of Capitol Reef National Park, Canyonlands National Park, Glen Canyon National Recreation Area and especially the



MAP OF THE STATE OF UTAH

HENRY MOUNTAINS
COAL FIELD

Figure 1. General Location of Henry Mountains Coal Field.

Study Site Photographs

Figure 2. View of Wildcat Mesa from the south end.

Figure 3. Looking southwestward on Pete Steele Bench.

numerous public campsites managed by state and federal agencies. Development of electric power generating facilities which may utilize coal from the Henry Mountain Coal Field or other nearby fields is also a current consideration. A new community to service a large uranium mining operation at Ticaboo Mesa is currently being planned by Ticaboo Development Co.

Most of the land in the general study area is federally administered by the Bureau of Land Management. Two state sections are on the margin of the coal field study area. The only private lands are those occupied by the Sandy Ranch and King Ranch.

C. Climate

The climate of the study area is arid. The predicted annual precipitation of Wildcat Mesa and Pete Steele Bench is between 8-9 inches and is highly variable from year to year. In the 1976-77 growing season essentially no effective precipitation occurred. Peak precipitation usually occurs during the period from July to October, a time when least effectiveness is possible. The frost-free season ranges from 120 to 150 days. Summer maximum temperatures of 100°F are common while winter temperatures may be as low as -10°F. Winds are usually from the west and southwest; average wind velocity is from 10 to 20 miles per hour. High wind velocities may occur in the spring and early summer. Under this harsh temperature - precipitation regime plant establishment and growth is severely limited.

D. Geology

The Henry Mountain area is located in the west central portion of the Colorado Plateau. The plateau system contains high escarpments, deep canyons, bare rocky badlands and laccolithic intrusions. Geologic strata are essentially horizontal. The coal fields study area averaging 5800 ft in elevation lies between the Henry Mountains to the east and the Circle Cliffs upwarp farther west. Central to the study area is the shallow valley of Sweetwater Creek, a northward-flowing tributary of the Fremont River. East of the creek is Pete Steele Bench and Apple Brush Flat, and to the west is Wildcat Mesa. These plateaus are pediment surfaces developed by runoff from Mt. Ellen on whose flank these graded surfaces lie.

A generalized description of the geologic nature of eight cores through the coal overburden indicates a predominance of sandstone with minor inclusions of organic matter or claystone which make up over 70 percent of the overburden. Silt and claystone strata make up less than 30 percent. A cycle of deposition is repeated numerous times in the profile. Sandstone grades upward into siltstone, then claystone, then into carboniferous shale, and finally to coal.

A chemical analysis of the core fractions indicates that all lithotypes are extremely deficient in available nitrogen and phosphorus. Potassium contents averaged higher in clay and silt lithotypes than in the sandy ones. Values for pH were mostly near 8.0 but some extremes were noted. Electrical conductivities ranged from .3 to 12.5 mmho/cm, but the general average was between 1 and 2. Boron, iron, copper, manganese and zinc values were not in the phytotoxic range, except in an unusual situation.

A greenhouse bioassay of core samples from each lithotype showed that only 3 of 181 samples of the various lithotypes were toxic to the growth of Russian wildrye1/. Production decreases in the test grass were noted when the pH of a lithotype dropped below 7.0, when EC_e exceeded 4.0 mmho/cm and when boron exceeded 1.0 ppm.

1/ Scientific names of plants mentioned in this report may be found in the appendix.

E. Coal

The coal that may be mined in this area is part of the Emery Sandstone Tongue of the Mancos Shale formation; the overburden is the sandstone and shales of the Emery Tongue. Limited observations available from the 8 core holes drilled suggest that the coal overburden varies from 0 to 200 feet west of core hole 5 on Pete Steele Bench (see Figures 11, 16 in main report). At core hole 5 the overburden is 268 feet deep lying over a 2-foot coal bed. On Wildcat Mesa the overburden does not exceed 150 feet except under the butte of Masuk Shale. Thickness of various coal seams was not emphasized in the EMRIA study. Outcrops of the coal may be seen in numerous places (Figure 4).

Chemical analysis of the coal by the USGS indicates that it is medium in heat value (9,000 - 10,000 BTU/lb) and generally less than 1 percent sulfur.

F. Soil

Twelve soil classifications were identified in the soil survey of the study area. These units range in character from rock outcrops to sandy stony loams to silty clays. The most suitable soils for rehabilitation purposes in the vicinity of the study site are soil mapping units designated as FaB, HaB and HaC. These soils are deep, with little or no rock or gravel. They presently support stands of native grasses and shrubs. However they are mainly fine sandy loams which are subject to wind erosion.

The NaB, MaB and JaA soils are moderately deep but become increasingly gravelly and rocky with depth. The BaD, BbF, PaD and RaF are very shallow and/or rocky. The GaD and GaG soils are very saline, shallow, marine-shale derived soils with little potential for supporting vegetation other than species of saltbush.

Figure 4. Outcropping of 7 to 8 foot thick coal bed on Pete Steele Bench escarpment along Dugout Creek.

G. Vegetation

Seven plant communities in the general area of the study have been mapped during previous land management surveys: grass, sagebrush, pinyon-juniper, saltbush, greasewood, desert shrub and half-shrub. These plant communities have a general tolerance to soil conditions and topographic features described in the soil survey. The composition of species, their limited density, and low percent cover reflect the general aridity of the region. These characteristics also serve as a guide to rehabilitation planning. Because of the adaptation of the existing species to the drought and salinity levels of the region they should be given highest priority for use in reestablishment. There are no identified endangered or threatened plant species on the study site or surrounding area.

Plant establishment studies on three major soil types and three geologic outcrops of the Pete Steele Bench escarpment indicate wide differences in plant survival under the extremely dry conditions of the 1976-77 growing season. Best survival on the outcrop types was obtained on a sandstone outcrop which occurs just above the coal seam at the base of Pete Steele Bench. The best survival among the soil types was a sandy soil on Wildcat Mesa.

H. Hydrology

Surface water in the study area, principally Sweetwater Creek and its tributaries, is supplied by snowmelt and springs at its headwaters, but below 5,000 feet elevation, the creek flows intermittently. The streams are generally dry except for short periods of flood immediately after local storms. At the present time, South and Dugout creeks are diverted for irrigation on the King Ranch. An estimate of the flows of these two creeks is 2 cfs of good quality water during spring and summer in years of normal precipitation.

Subsurface water is postulated from eight waterbearing sandstones within the Henry Mountains area. The strata with the greatest potential is the Navajo Sandstone because of its thickness, better sorting and relatively better porosity than the other sandstones. Although there is some indication that the Navajo Formation may be saturated and under artesian pressure, the likelihood of obtaining any significant rate of flow from it is low because of a predicted slow release of water from the sandstone. Where fractures of the Navajo Formation occur, such as in the Salt Wash area proposed for use by the Intermountain Power Plant, a considerable flow volume has been tested.

Water quality may vary from a few hundred parts per million to tens of thousand parts per million of dissolved solids based on data obtained from wells in the Navajo Formation in other locations.

Sedimentation values for the study area are not available, nor are values from unreclaimed spoils. Sediment yields determined for the generalized Colorado region range from .2 to 1.0 acre feet/mile^2 per year. The generally low value for plant cover of the various plant communities, erosive nature of the soil and topographic features (slopes) of the study area may be expected to yield high sedimentation rates.

I. Wildlife

In spite of the generally dry nature of the study location and general area, topographic variation and numerous vegetation types provide for a diversity in wildlife. Important wildlife species are bison, deer, mountain lion, many species of birds, small mammals and invertebrates.

No endangered or threatened species of animals are known to exist in the Henry Mountains. The closest relevant sightings of endangered wildlife found near the study site is the black-footed ferret, 75 miles to the north, and a possible nest of the peregrine falcon in Capitol Reef National Park (Utah Division of Wildlife Resources, 1977).

J. Visual

Visual access to areas of possible mining activity from Capitol Reef National Park would be minimal. Roads causing the generation of dust could be seen although not with significant resolution. Areas of Dixie National Forest or the Henry Mountain Peaks were not evaluated for visual access to the possible mining sites because of the topographic enclosures created by the escarpments of Wildcat Mesa on the west and Pete Steele Bench to the east, plus the distance associated with possible view sights.

K. Present Land Use

Present land uses in the Henry Mountain Coal Field area, though numerous, are at a low intensity. Grazing is the principal use and is important to the economic base of Wayne and Garfield counties. Steele Butte allotment provided 3166 animal unit months (AUM) of grazing in the year 1973-74 on an area where 34 percent of the land is judged to be in a downward range condition trend and 75 percent is in an unsatisfactory ecological condition. Range improvement practices of chaining and seeding employed on Tarantula Mesa raised range carrying capacity from 26 to 29 acres/AUM to 2 acres/AUM during favorable years and 26 acres/AUM in unfavorable years.

Recreation has a high potential for increase in future years. As a non-consumptive use it brings economic benefits into the region. Touring and sight-seeing followed by camping and hunting are typical uses in the Henry Mountains Resource Area. An average count of 100 vehicles per day going south from Highway 24 on the Notom road has been reported.

Watershed as a land use must be considered, although the water flow from Sand Creek and Sweetwater Creek to the Fremont River is very limited and intermittent. Water in the immediate study area is heavily depended upon by the Sandy and King ranches.

Wildlife use of the land, vegetation and water of the region is universal. The 200-head bison herd normally seeks the higher reaches of the Henry Mountains in summer but migrates to Tarantula Mesa and Cave Flat in winter months. They may use other areas depending on the nature of the weather and feed availability. Deer, mountain lion and numerous small mammals are residents of the various habitats in the general area of consideration.

L. Objectives of Reclamation

Objectives for land rehabilitation are covered in federal and state regulations. Applicable federal statutes include the following:

National Environmental Policy Act of 1969 (PL 91-190)
Surface Mining and Control Act of 1977 (PL 95-87)
Federal Land Policy and Management Act of 1977 (PL 94-579)

Utah State regulations for reclamation are covered in the Utah Mined Land Reclamation Act of 1975.

M. Recommendations for Reclamation

Given the harsh environment of the region, rehabilitation of disturbed land caused by surface mining would have to be accomplished with the greatest care and with appropriate methods. Existing methodologies may be inadequate to meet the harsh conditions of the area and will have to be modified. New methods or information may have to be developed through site-specific studies. The following general recommendations are provided:

1. The most suitable mix of land uses subsequent to mining should be planned as a guide to rehabilitation measures and needed research.

2. Mining activities should be conducted to permit utilization of favorable overburden strata individually or mixing of several strata for use in revegetation. Data from bioassay and chemical analyses should help to identify suitable overburden strata. Mining activities should also be kept localized and consider visibility aspects in construction and maintenance of roads.

3. Soil and overburden placement should emphasize the use of FaB HaB or HaC soils and/or overburden strata that meet specified criteria. Subsurface materials used under topsoil should not create problems of instability and toxicity.

4. Reconstitution of a soil profile for optimum plant growth should receive a high priority. Criteria for soil with favorable permeability, water holding capacity, fertility and texture characteristics should be established from existing information and/or in site studies.

5. Shaping of spoils should be compatible with surrounding topography to the extent practicable with necessary deviations to accommodate water harvesting potentials, habitat diversity, safe sites for plant establishment and aesthetic quality. Orientation of slopes to utilize favorable insolation possibilities is recommended.

6. Surface mulching with available material for improvement of soil characteristics as well as surface stabilization for water harvesting and dust control should be included in the rehabilitation plan.

7. Compaction of the soil-spoil surface should be avoided or ameliorated to promote infiltration and root penetration. Infiltration

characteristics of the reconstituted soil should be studied and specified for optimum land rehabilitation.

8. Vegetation establishment techniques should be tailored specifically for the harsh sites and climate that exist in the general area. Principal recommendations include:

   a. Mulch to increase soil moisture and fertility functions.
   b. Direct seed only if irrigation is used.
   c. Select mixtures of native plant species adapted to area.
   d. Give priority to transplanting of high quality bare-root or container grown native plants for preliminary rehabilitation phase.
   e. Avoid high density plantings to reduce competition for water and, where necessary, control competing annual plants.
   f. Maintain a high priority for natural aesthetics in time, space, shape and color in planning the seeding or planting arrangements.

9. Develop sources of irrigation water from the limited surface or ground water supplies. Consider the limitation imposed by inadequate water supply but develop information on the amounts of water that may be obtained from water harvesting, impoundment of surface waters (including purchase of rights) and drilling of a deep well.

10. Ameliorate impacts on wildlife by maintaining a compact mining operation, restrict travel to unused or future mining areas, provide water for wildlife, improve habitat carrying capacity for various species and seek cooperation with the Utah Division of Wildlife Resources in mitigating wildlife impacts.

11. Fertilize all areas to be seeded or planted with nitrogen, phosphorous, and potassium.

12. Avoid high structures and equipment in mining activities to reduce visual impacts.

13. Manage planted or seeded areas during establishment to avoid grazing by wildlife and livestock. Protection for an extended period may be necessary.

14. Studies to provide needed information about the site and serve as a basis for modification of current mining and reclamation techniques are recommended as follows (Priority listing is not intended):

    a. Drill a test well into the Navajo Sandstone to determine flow rate and water quality.
    b. Determine plant establishment methods suitable for the general area.
    c. Determine methods for control of small mammals to keep them from destroying new plantings.
    d. Assess mix of land use priorities suitable for the post-rehabilitation period.
    e. Develop better ways for reconstruction of the soil profile from topsoil and geologic strata available in the area for optimal soil moisture conditions.
    f. Identify critical recreational view sites in locations adjacent to the mining area.
    g. Develop mining methods to improve selection and storage of desirable overburden strata or mixing of all strata.
    h. Develop criteria for optimum vegetation parameters that would be used in specifying revegetation standards.

II. INTRODUCTION

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The ever-present need for energy resources to power the growing technological society of the United States, coupled with the dwindling world-wide supply of petroleum and natural gas, places a great demand on the federal government to foster the development of coal to replace oil and natural gas whenever feasible. The nation's known coal reserves are extensive, estimated to be 3.21 trillion tons (Averitt, 1967); of this, where the overburden is from 0 to 3,000 feet thick, 1.56 trillion tons have currently been mapped and explored. In the interior western United States, the total identified coal reserves, located reasonably near the surface (0 - 3,000 feet), are 888,224 million tons. Capability for surface mining usually depends upon thickness of the coal in relation to depth of the overburden. Assuming 200 feet of overburden as the upper limits under present technology, approximately 27 billion short tons are considered strippable in the western states (Study Committee on the Potential for Rehabilitating Lands Surface Mined for Coal in the Western United States, 1974). The largest strippable reserves are located in Wyoming; the second largest are in Montana. In Utah, portions of the Alton, Kaiparowits, Emery and Henry Mountains fields have potential for surface mining.

Western coals are generally favored for use because of their low sulfur content and relative ease of recovery by present surface mining techniques. However, surface mining will present severe problems for land rehabilitation in this arid region. Any proposal to surface mine a deposit of coal should also include an analysis of the potential for rehabilitation and recommendations for action based on actual site conditions.

The Bureau of Land Management is responsible for the administration of extensive land areas where coal deposits are located. To meet national goals of increasing coal production and also to develop sound program guidelines for land rehabilitation, the Bureau of Land Management has developed a process for problem analysis and the formulation of recommendations called Energy and Mineral Rehabilitation Inventory and Analysis (EMRIA). This report is Number 5 in this series of studies.

A. Purpose

The purpose of this study is to provide a single source of general baseline information for the development of objectives for optimum rehabilitation and revegetation. It also provides data and interpretations that may be used in pre-planning site-specific lease stipulations for mining and reclamation.

B. Objectives

The objectives of the EMRIA study are:

1. To analyze and quantify environmental impacts relative to surface mining of coal from the Henry Mountain study site in Wayne County, Utah.

2. To provide resource and impact information to the leasing-site selection procedures as set forth by the Secretary of the Interior.

3. To provide environmental resource information needed to implement effective reclamation and rehabilitation programs leading to the development of meaningful lease stipulations as required by the Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87).

4. To provide resource and impact information needed by state and interagency task forces who provide information and assist with local, state and regional development and land-use planning efforts.

5. To determine the present and potential capability of the surface soil and sub-surface geologic materials to support and maintain vegetation in a specific area of the study which can serve as the basis for extrapolation to the general area of the coal field.

6. To provide physical and chemical data from which realistic stipulations may be prepared for coal exploration, mining, and reclamation plans.

7. To provide data needed in the preparation of Environmental Impact Statements, Environmental Analysis Records, and to aid in the preparation and review of mining and reclamation plans for land disturbing activities in the general area of the study.

C. Authority

This report was prepared under authority of the Public Land Administration Act of July 14, 1969, (74 Stat. 506).

D. Responsibility

The responsibilities of various institutions for the development and preparation of this report are as follows:

1. Bureau of Land Management

a. To select study areas, with advice from United States Geological Survey, for investigation of vegetation, soil, geological structure, surface water, and ground water.

b. To provide access to study sites, monitor geologic exploration, and plot research for land-use compatability and protection of surface environment.

c. To provide a contract officers' representative to coordinate the work of this study team including on-site activities and provision of agency's information.

d. To provide relevant information from reports, files, and program plans dealing with various aspects of the agency's resource management activities.

e. To participate in data review and workshop to formulate recommendations.

f. To review draft of report and make recommendations for final copy.

2. Utah State University

a. To develop the study plan and inventory of available information, and to investigate study sites utilizing resource specialists, including representatives of the BLM and Soil Conservation Service.

b. To subcontract with a competent geological drilling company to drill eight exploratory holes on sites selected by BLM and United States Geological Survey.

c. To provide geological monitoring of drilling and logging of cores, geological interpretation of strata, analysis of core fractions and biological testing of selected core samples under greenhouse conditions.

d. To perform field studies of plant establishment and growth potential on soils and geologic outcrop materials which can be compared with results from the greenhouse bioassay and chemical analyses.

e. To analyze the environmental problems related to development of the Henry Mountains coal field to make recommendations for appropriate rehabilitation techniques.

f. To prepare a report of the problems, analyses, and recommendations.

3. Other Public Agencies

a. U. S. Soil Conservation Service: To provide results of a soil survey of the Henry Mountains coal field area.

b. U. S. Geological Survey: To provide services of a geologist to monitor the geological core drilling operation and to submit relevant data from the cores. Also, to provide the report of their consultant, Dr. Henry Good, who studied the subsurface hydrology of the study area.

c. National Park Service: To provide information on present and projected recreation uses of the region.

d. No responsibility is implied for the participation of other public agencies, except an obligation to provide relevant information to the Utah State University study team.

E. Location

The study area is located in south-central Utah, about 190 air-line miles south southeast of Salt Lake City, in Garfield County (Figure 5). It is reached by traveling south from Salt Lake City via Nephi, Gunnison and Salina to Sigurd, then by following Utah Highway 24 south-easterly through Capitol Reef National Park to the Notom turnoff. The unpaved road south past Notom leads to Sandy Ranch, then forks southeasterly to the study area.

The Henry Mountains coal field, (Figure 6) of which the study area is a part, is preserved in the Henry Mountains syncline between the Henry Mountains to the east and the Water Pocket fold to the west, parts of the Canyonlands section of the Colorado Plateaus.

MAP OF THE STATE OF UTAH

HENRY MOUNTAINS
COAL FIELD

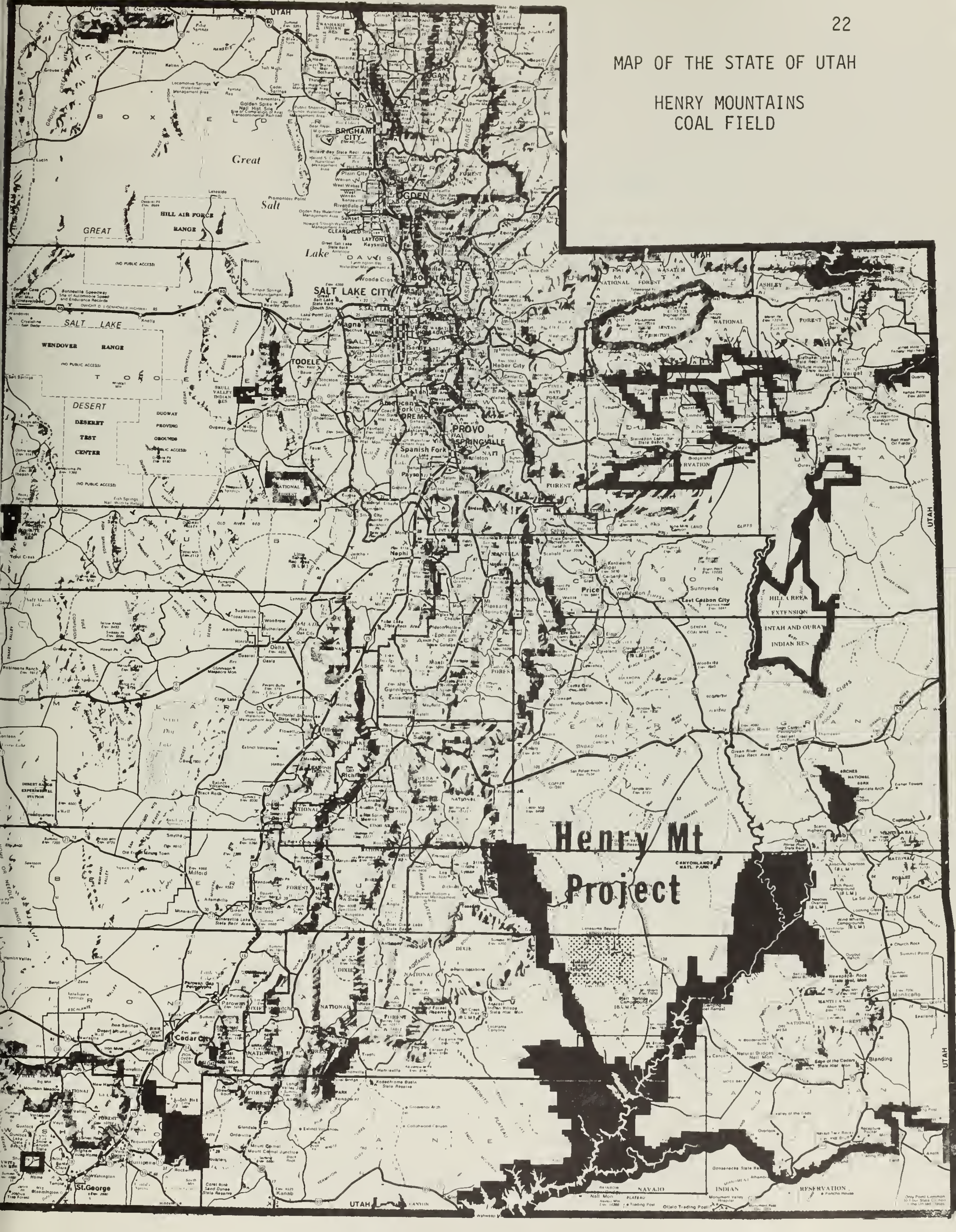
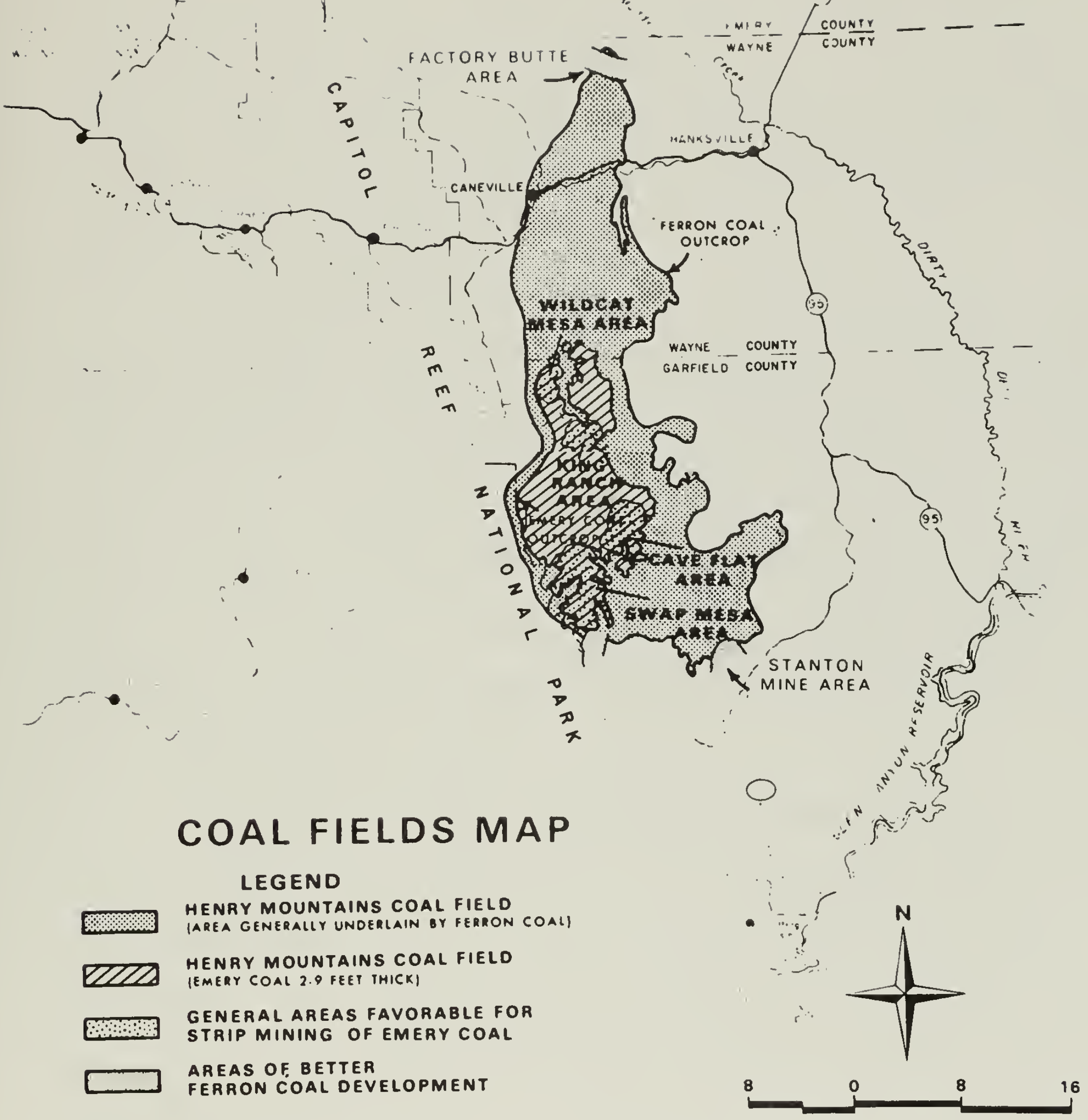


Figure 5. General Location of Henry Mountains Coal Field.



SOURCE U G & M S MONOGRAPH No 2, EASTERN UTAH COAL FIELDS

Figure 6. General area of Henry Mountains Coal Field.

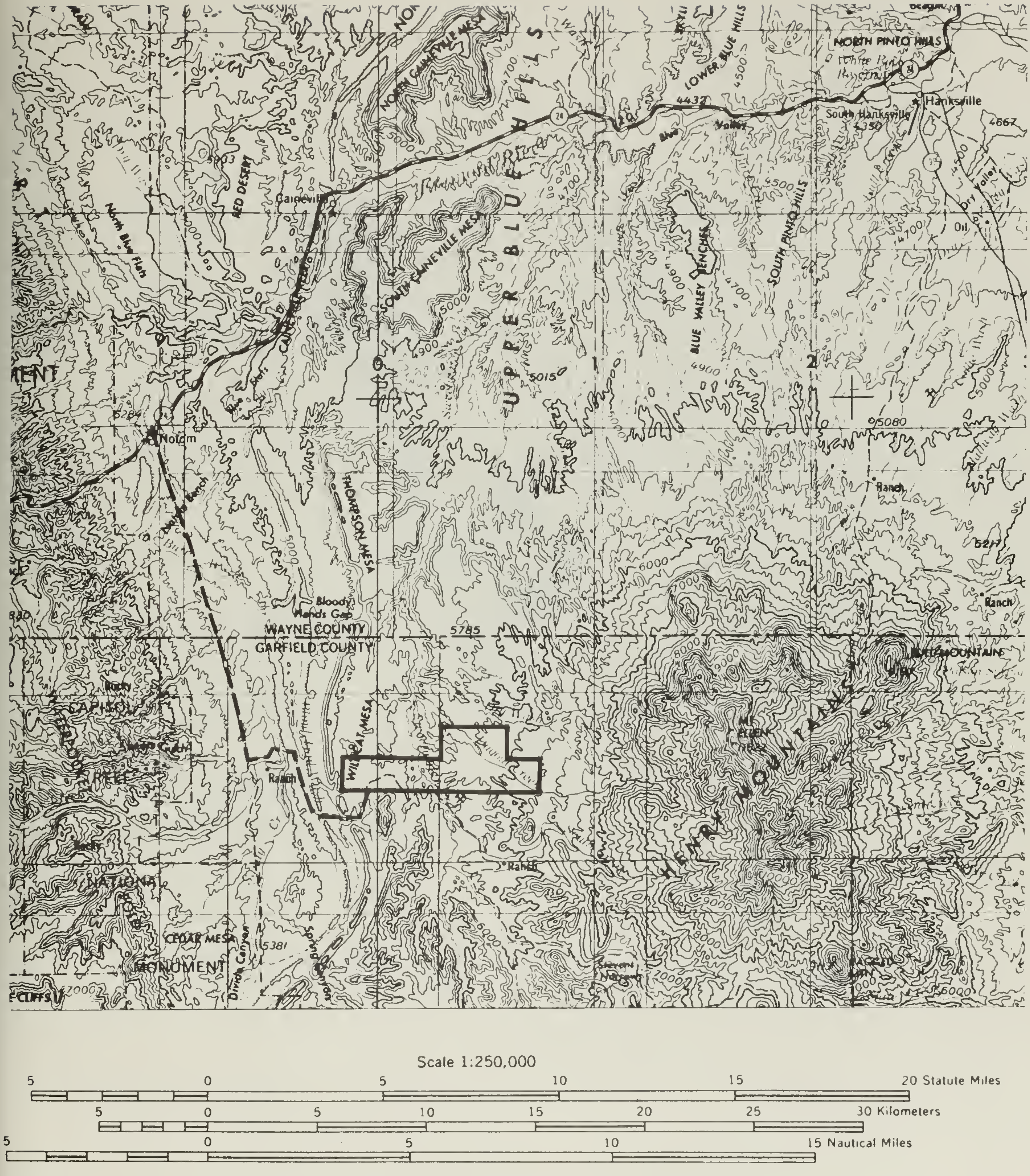
Specific study areas were identified in the vicinity of Wildcat Mesa and Pete Steele Bench. This general study location is approximately 15 miles south of U. S. Highway 24 between Fruita and Hanksville, Utah. Individual study sites are approximately 4 miles east of Sandy Ranch. Sections designated for geologic overburden and land rehabilitation studies include 17, 18, 19, 20, and 21, (T 31 S R 9 E) and 22 and 23 (T 31 S R 8 E) (Figure 7).

The eight holes drilled for geologic overburden studies were located not by the study team, but by the representatives of the Geological Survey and the Bureau of Land Management, who also assigned them the numbers 1, 2, 3, 4, 5, 7, 9, and 15. A much larger area has been explored for coal by Meadowlark Farms which acquired twelve prospecting permits in 1967 for 5,120 acres on Wildcat Mesa, 1,920 acres on Cave Flat, and 4,320 acres on Swap Mesa from the Cayman Corporation (Figure 8).

F. Historical Perspective

Early human habitation in the Henry Mountains region was by the Basket Makers in about 2000 B. C. Other Indian groups which followed the Basket Makers were the Pueblos and more recently the Piutes (Woodbury, 1950). Archeological sites may be found in the general region where cliff faces and rock overhands provided sites for constructing shelters and storage bins. In 1853, John C. Fremont viewed the area during his expedition down the Colorado River. Later, John Wesley Powell described the Indian dwellings constructed on ledges at the base of overhanging cliffs (Powell, 1895).

Opportunities for cattle grazing on the Henry Mountains and the low desert between the mountains and Capitol Reef attracted settlers from the Boulder-Escalante area and led to the development of livestock



CONTOUR INTERVAL 200 FEET
WITH SUPPLEMENTARY CONTOURS AT 100 FOOT INTERVALS

TRANSVERSE MERCATOR PROJECTION

SALINA UTAH NJ-12-5

Figure 7. Specific study area approximately 15 miles south east of U.S. Highway 24.

Source U.S GEOLOGICAL SURVEY

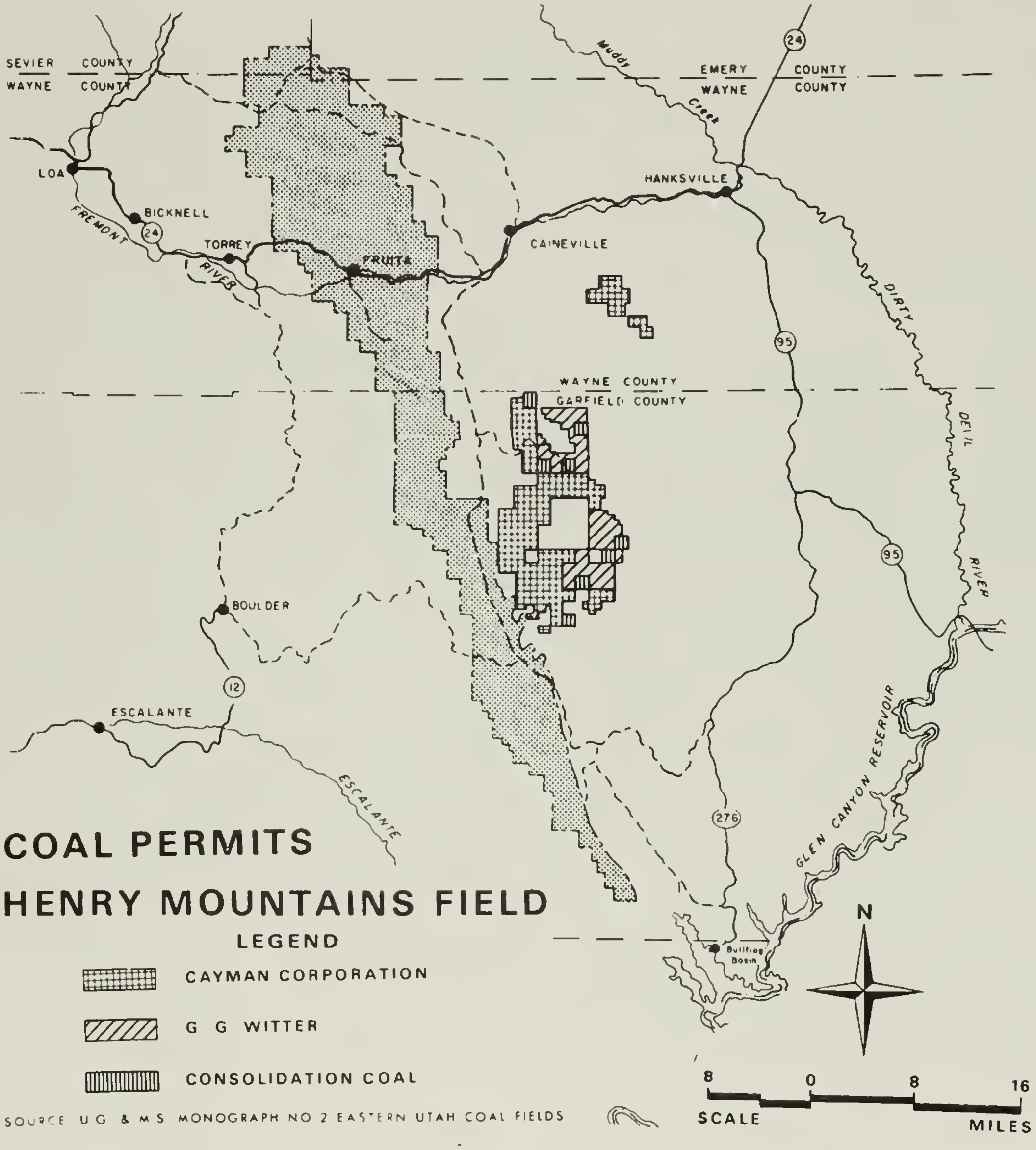


Figure 8. Coal Permits on Henry Mountains Coal Field.

drive routes such as the Burr Trail. Pioneers traveled through Capitol Gorge (a part of present day Capitol Reef National Park) in 1884 on their way to settle the flood plains of the Fremont River. Settlements such as Hanksville and Caineville resulted from these migrations. Ranches at Notum and Sandy Wash testify to the determination of ranchers to stay with the land in the face of hardships and loneliness. Early settlers made limited use of coal outcrops. Evidence of early mines exists in tunnels excavated at Dugout creek, Dry creek and north of Factory Butte.

Uranium prospecting and mining since 1948 has resulted in many of the present day 4-wheel drive roads and trails in the Henry Mountain region. Although the area has been studied geologically and mined since the turn of the 20th century, only after World War II uranium prospecting and mining opened up much of the area for general travel. A paved road through Capitol Reef to Hanksville was constructed in 1962.

Some of the early fame of the Henry Mountain-Hanksville area stems from the legendary exploits of the Butch Cassidy gang who hid out in the Robber's Roost area between the Dirty Devil River and the Green River. Recent fame of the region comes from the recreational attraction of Lake Powell with such marinas as Bullfrog, Hite, and Hall's Crossing. More recently, controversy over the location of a large coal-fired electric power plant designed to utilize coal from the Kaiparowits Plateau has made the region a focal-point for concern about development versus the aesthetic beauty and recreational use of the general region.

G. Socio-Economic Factors

The Henry Mountains area is one of the more remote and undeveloped areas of Utah. The estimated 1976 population of Garfield and Wayne counties was 3,500 and 1,700 respectively, according to the Utah Population Work Committee (Brockert, 1976). Wayne county population is estimated to have increased by 200 between 1970 and 1972 -- an 11 percent increase.

The labor force in Wayne county in 1975 was estimated to be 871 of which 374 were non-agricultural workers earning an average annual income of $2,403 per person. The average personal income was estimated to be $4,900 per capita (Watanabe, 1976).

Garfield county population was estimated to have increased by 400 since 1972, an 11 percent increase. The average labor force, located almost entirely in the western end of the county, was estimated to be 1,582 in 1975. A large proportion of the labor force, 1,114 persons, was non-agricultural earning an average annual income of $6,859. The average yearly personal income for all occupations was $4,100 per capita (Watanabe, 1976).

The principal communities in the region of Henry Mountains are Hanksville, Bicknell, and Loa, with 1970 populations of 181, 276 and 324 respectively. Numerous smaller settlements and ranches are located within the area, but these depend on the three larger communities for services. Much of the commercial activity serves a growing recreation industry. Motels, restaurants, gas stations and grocery stores depend heavily on tourism/recreation, associated primarily with Capitol Reef National Park and the Bullfrog Marina on Lake Powell for income. Table 1 provides a comparison of visitor days at the major parks and monuments in the West. Other source of economic activity are from agriculture (principally grazing), mining, and public agency payrolls generated by land management activities.

Although the study sites and principal areas of interest in the Henry Mountain coal field are located in Garfield county the general area of the coal field extends north into Wayne county. Equally important is the presence of services and population in Wayne county which would be economically and socially affected by development of the Henry Mountain coal field. Wayne county is in the central Utah planning area along with Piute, Sanpete, Juab, Sevier, and Millard counties. Garfield county is in the southwestern county planning area, which includes Kane, Washington, Iron, and Beaver counties.

H. Developments in the Region

There are no commercial developments in the immediate study area of the Henry Mountains coal field although a surface mining operation started in late 1977 in T 29 S R 9 E Section 2.

Establishment of Capitol Reef National Monument as a National Park in 1971 began a trend of increasing tourist trade. For example, 272,040 visitors were counted in 1972, but by 1976, the number had nearly doubled to 469,619 visitors (Table 1). The development of Lake Powell as a recreational resource has increased the number of tourists visiting the region. In 1976 over a million visitors came to the Glen Canyon National Recreation Area. Two points of entry in the vicinity of Henry Mountains are the marinas at Bullfrog Basin and Hite.

Currently under consideration, but by no means settled at the time of this report, is the proposal by Intermountain Consumers Power Association (ICPA) for construction of a 3,000 mega-watt coal-fired electric power generating plant on Salt Wash, about midway between Factory Butte and Capitol Reef National Park. According to a preliminary report of the Utah Geological and Mineral Survey (Kalliser, 1977), one of

Table 1. Yearly visitation totals at selected national parks, monuments in the Western United States.

	1972	1973	1974	1975	1976
Arches National Park	225,510	276,011	171,313	237,915	294,779
Bryce Canyon National Park	426,151	431,044	410,307	579,331	626,207
Canyonlands National Park	60,757	62,574	58,988	71,774	
Capitol Reef National Park	272,040	311,197	233,975	292,093	469,619
Cedar Breaks National Monument	265,983	201,311	274,694	360,179	415,587
Glen Canyon National Recreation Area	970,922	1,209,000	1,158,203	1,139,275	1,061,716
Grand Canyon National Park	2,707,516	2,064,300	2,208,194	2,754,791	3,026,235
Natural Bridges National Monument	42,724	40,300	40,300	48,431	71,865
Rainbow Bridge National Monument	73,526	57,100	55,104	65,171	81,875
Grand Teton National Park	3,002,230	3,083,315	2,936,756	2,807,027	3,921,326
Yellowstone National Park	2,261,600	2,066,218	1,937,768	2,246,132	
Zion National park	970,167	1,087,397	941,313	1,164,556	1,222,404

Source: National Parks office in Salt Lake City, Utah.

the possible sources of coal for a power plant at the Salt Wash site, or alternative sites in the vicinity north of Hanksville, would be the Henry Mountains field. The environmental studies for the proposed Intermountain Power Plant (IPP) are currently considering two alternatives identified by the Interagency Task Force on Power Plant Siting in Utah. The two alternative sites are 2-5 miles north of Hanksville and near the town of Lynndyl in west central Utah.

Also currently under consideration is a proposed subdivision in eastern Garfield county located approximately ten miles north of Bullfrog Basin and four miles southwest of the Little Rockies in the Henry Mountains. The proposed subdivision would be developed by the Ticaboo Development Corporation and would supply the necessary community facilities and services for approximately 170 to 200 Plateau Resources Limited uranium mine and mill workers and their families. An additional 25 to 30 families are expected to supply secondary services for the subdivision and the nearby Bullfrog Basin Marina. The projected population of the Ticaboo subdivision, when the mine and mill are in full operation, would be between 645 and 757 residents.

The Plateau Resources Limited owns and operates a uranium mine approximately five miles northwest of the proposed subdivision site. The company plans to construct a uranium processing mill with a 750 ton per/day capacity and increasing the company's employment from the present 75 to 80 mine workers to the proposed 170 to 200 mine and mill workers.

I. Land Status

Most of the land in the Henry Mountains regions is under federal agency jurisdiction and management (Figure 9). Most land is managed by the Bureau of Land Management, including the Henry Mountains and the

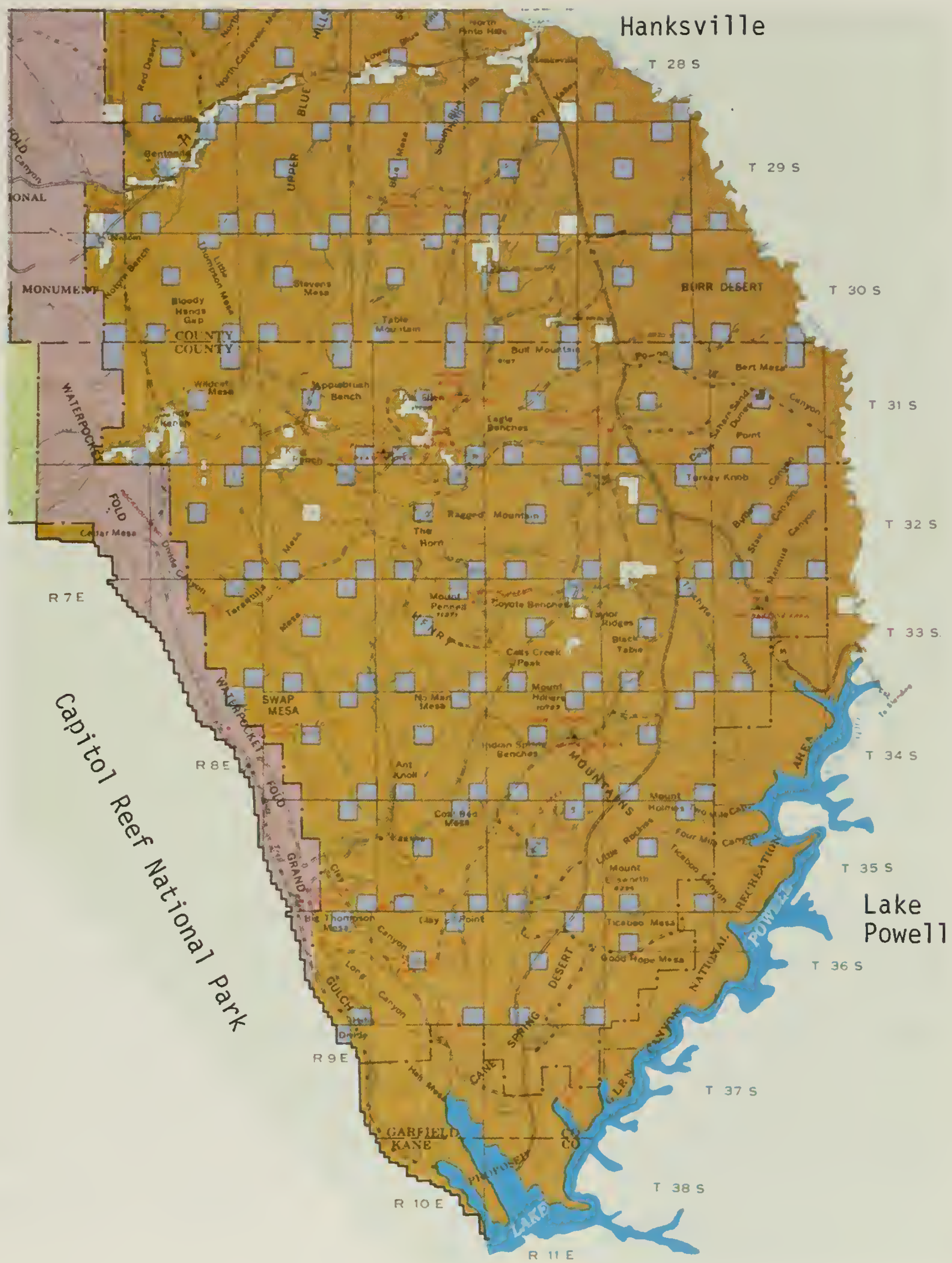


Figure 9. Land status in the vicinity of the Henry Mountains Coal Field. Darkest grey shade are land administered by the Bureau of Land Management. State lands are medium gray. Private lands are white.

Source: Bureau of Land Management

mesas and low desert between Henry Mountains and the Water Pocket Fold. State lands are regularly located as sections 2, 16, 32 and 36 in each township. Private lands generally are located in strategic areas along water courses for irrigation, such as along the Fremont River or at spring sites, such as the Sandy Ranch, King Ranch, and Notum Ranch. Adjacent lands managed by the National Park Service include 218,559 acres of Capitol Reef National Park and Glen Canyon National Recreation area. Farther west, Boulder Mountain and Aquarius Plateau are lands administered by the U. S. Forest Service.

J. Mineral Status

The currently known mineral resources of the Henry Mountains area are those related to energy production. Coal, uranium, and tar-impregnated sandstone are the three energy resources of interest in the general study area. Figure 10 depicts the location of energy minerals in the Henry Mountains area as presented in Energy Resources maps of Utah (Utah Geological and Mineral Survey, 1975).

Coal fields are located to the west and north of the Henry Mountain peaks. Uranium deposits (Johnson, 1959) have been identified in a ring around the base of the mountains. Tar-impregnated sandstones are found on the west boundary of Capitol Reef National Park. Limited potential for petroleum exists in the southern extension of the east park boundary in township 34 S Range 8E.

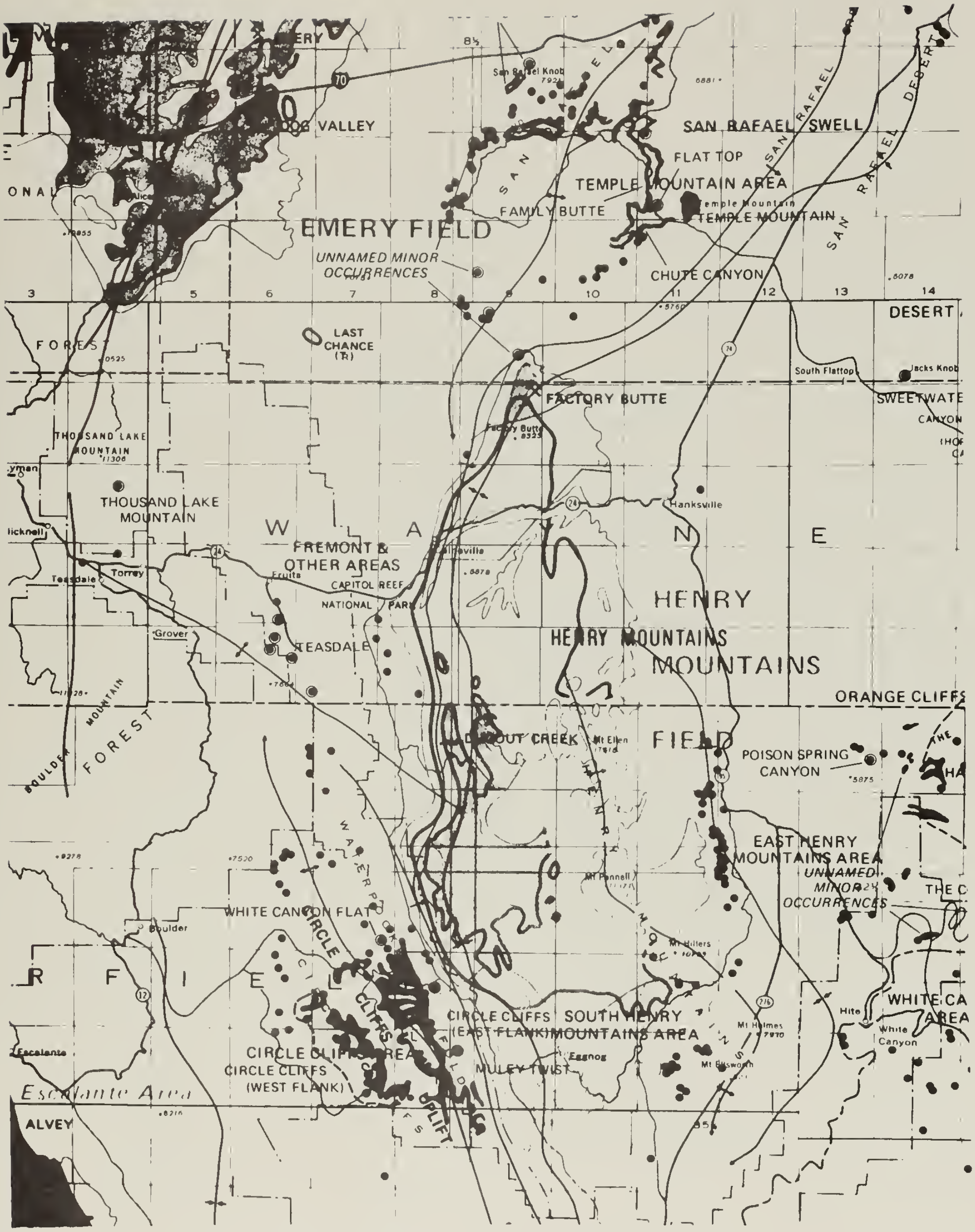


Figure 10. Energy resources in the Henry Mountains Coal Field area. Shaded areas are coal fields. Dark circles are uranium deposits. Dark areas in circle are cliffs area.

Source: Map 36, Utah Geological and Mineralogical Survey

III. PHYSICAL PROFILE

A. Climate

B. Physiography

C. Topography

D. Geology

E. Coal

F. Soil

G. Vegetation

H. Sedimentation

I. Hydrology and Water Supply

J. Wildlife

K. Cultural

L. Archaeology

M. Visual Prominence

III. PHYSICAL PROFILE

A. Climate

The climate of the study site is arid. Precipitation is low and highly variable from year to year. A regression equation, relating precipitation at existing stations with elevation based on 8 years of data at 10 locations, predicts the average annual precipitation to be only about 8 to 9 inches on Wildcat Mesa and Pete Steele Bench (elevations 5,600 - 6,100 feet; Table 2). Although the average annual precipitation for a 10 year period at Sandy Ranch, located just west of the study site at an elevation of 5,200 feet, was 7.7 inches, the extremes were 5.31 and 11.40 inches (Table 3). The high variability of precipitation in the region is further demonstrated by 38 years of data from Hanksville (elev. 4,300 feet; Table 4).

Extended drought periods of 3 years or more are common. Peak precipitation on the average occurs in July and August (Table 5). The summer months are also the time of highest temperatures and greatest evapotranspiration potential. Pan evaporation data from files of the Utah State climatologist for Capitol Reef at an elevation of 5,500 ft. indicate a potential evaporation of 64.8 inches from May ot October. The frost-free season ranges from about 120 to 150 days. Summer temperatures can exceed 100°F, and winter temperatures can be as low as -10°F.

Wind direction and velocity information for the study area are not available but the generalized regional flow pattern is westerly according to the Kaiparowits final environmental impact statement (USDI Bureau of

Table 2. Actual and predicted precipitation at various elevations in the Henry Mountains Coal region. (Data from Henry Mts. Unit Resource Analysis, BLM)

Location	Elevation (feet)	Mean Annual Measured Precipitation 8-1-65 - 7-31-73	Predicted Annual Precipitation
Hanksville	4300	5.79 inches	5.36 inches
Poison Wash	4900	5.38	6.65
Sandy Ranch	5200	7.73	7.29
Thompson	5200	7.30	7.29
Bitter Creek	5800	8.50	8.58
Apple Brush	5900	7.89	8.80
Starr Spring	6100	8.44	9.23
Tarantula Mesa	6100	10.34	9.23
Eagle	6600	11.85	10.30
Hancock	8900	14.77	15.25
Wildcat Mesa and Pete Steele Bench	5600-6100		8.15-9.23

Prediction equation: $y=.002149\ x - 3.88099$ $r^2 = .899$

where y = annual precipitation in inches and x = elevation in feet

Table 3. Monthly precipitation at various locations in the Henry Mountains Planning Unit (Computed by B.L.M. from U.S. Weather Bureau Data).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Station: Hanksville (1931-72) 4200 ft.													
Mean	.25	.23	.27	.35	.35	.33	.60	.89	.51	.70	.31	.33	5.22
Percent Annual	4.9	4.5	5.3	6.8	6.8	6.4	11.8	17.5	10.0	13.6	6.0	6.4	100
Mean Maximum	.48	.43	.51	.88	.66	.73	1.43	1.78	.87	1.30	.75	.81	7.19
Mean Minimum	.07	.06	.10	.11	.11	.09	.26	.36	.14	.23	.08	.13	3.76
High	1.20	.83	1.58	2.38	1.00	1.35	2.92	2.96	1.92	3.58	1.67	1.54	9.76
Low	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.34
Station: Hite (1943-62, 1968-72)													
Mean	.47	.44	.44	.41	.36	.35	.42	.58	.45	1.07	.54	.65	6.18
Percent Annual	7.6	7.1	7.1	6.6	5.8	5.7	6.9	9.3	7.3	17.3	8.7	10.5	100
Mean Maximum	1.16	1.02	.87	.91	.65	.91	.96	1.25	1.15	2.36	1.11	1.11	8.58
Mean Minimum	.20	.19	.12	.14	.13	.04	.13	.25	.17	.42	.17	.22	3.60
High	2.42	2.17	1.47	2.01	1.79	1.86	1.50	2.17	2.22	5.46	1.54	1.77	12.12
Low	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.73
Station: Bullfrog+ (1967-72)													
Mean	.23	.27	.32	.06	.27	.31	.50	.38	.30	1.83*	.62	.42	5.51
Percent Annual	4.0	5.0	6.0	1.0	5.0	6.0	9.0	7.0	5.0	33.0*	11.0	8.0	100
High	.86	.91	1.11	.25	1.01	1.03	1.75	.51	.72	6.53	1.24	1.12	10.49
Low	.00	.00	.00	.00	.00	.00	.00	.16	.02	.02	.07	1.5	2.17
*1972 storm 6.53"													
Station: Sandy Ranch + (1963-72) 5200 ft.													
Mean	.33	.48	.38	.50	.67	.44	1.02	1.25	.58	.87	.43	.75	7.70
Percent Annual	4.3	6.2	4.9	6.5	8.7	5.7	13.3	16.3	7.5	11.3	5.6	9.7	100
High	1.51	1.83	.71	1.38	1.43	1.14	1.63	2.54	1.26	5.48	1.43	2.32	11.40
Low	.00	.00	.00	.00	.00	.00	.29	.35	.00	.00	.00	.00	5.31

+ Mean Maximum, Mean Minimum not computed - Insufficient years.

Table 4. Years with below or above average precipitation at Hanksville, Utah (Elevation 4300 ft.; 1931-42 and 1945-72). 1/

BELOW AVERAGE* PRECIPITATION

Consecutive Years "Below Average" precip.	Number of Occurrences	Total Years
4	1	4
3	5	15
2	0	0
1	5	5
		24

ABOVE AVERAGE* PRECIPITATION

Consecutive Years "Above Average" Precip.	Number of Occurrences	Total Years
3	1	3
2	3	6
1	7	7
		16

* Average = 5.22"

1/ Source of data: Henry Mts. Unit Resource Analysis (USDI Bureau of Land Management, 1975)

Table 5. Monthly temperatures at various locations in the Henry Mountains Planning Unit (computed from U.S. Weather Bureau Data by BLM).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Extremes		Days Between		
														High	Low	24^0	28^0	32^0
Hanksville[1] (1931-72) 4300 ft.																		
Mean Max.	39.0	48.6	60.1	71.2	81.0	91.3	96.7	93.5	85.1	72.2	57.1	43.8	70.0					
Mean Min.	8.4	17.9	27.0	34.8	42.9	51.4	59.1	55.9	46.7	33.9	20.9	12.9	34.3					
Mean	25.9	33.9	42.5	52.9	62.9	71.9	79.4	76.9	67.6	54.7	39.4	28.9	53.1	105	-8.2	202	186	164
Hite[2] (1948-62, 1968-72)																		
Mean Max.	46.8	54.7	65.1	74.2	83.4	94.2	99.5	97.7	88.5	75.4	60.9	46.1	73.9					
Mean Min.	24.7	30.0	37.3	44.3	52.9	61.3	68.8	67.9	56.4	43.9	34.0	24.3	45.5					
Mean	37.4	42.9	50.2	60.1	69.6	78.5	85.6	83.5	75.4	66.8	47.5	38.0	61.3	107	13.0	271	248	230
BullFrog[3] (1967-72)																		
Mean	35.4	43.7	50.9	57.1	68.6	78.1	85.1	82.6	73.3	59.1	46.0	34.0	59.6	107	7.0	280	240	213
Sandy Ranch[3] (1963-72) 5200 ft.																		
Mean	27.3	33.2	41.7	48.2	58.8	67.5	75.4	73.1	63.1	52.2	38.9	27.4	50.6	101	-10.0	173	158	138

[1] Mean maximum & minimum based on 38 years, mean 40 years
[2] Mean maximum & minimum based on 14 years, mean 19 years
[3] Length of record - mean maximum and minimum excluded.

Land Management, 1976). Average afternoon wind speeds measured at 7,300 ft. above mean sea level over Page, Arizona in January (1970-1973) were 45 miles per hour. In October, wind speeds of 40-45 miles per hour were measured (Spangler et al 1974). Wind speeds greater than 20 miles per hour are almost entirely from the west and southwest. Highest seasonal velocities occurs in the spring and early summer (USDI Bureau of Land Management, 1976).

B. Physiography

The Henry Mountain area is located in the west central portion of the Colorado Plateau. The plateau system contains high escarpments, deep canyons, bare rocky badlands and laccolithic intrusions. Geologic strata are essentially horizontal; tilted beds in the region are limited essentially to monoclines and borders with a few local uplifts (Tidwell, 1972). The steep cliffs of table lands resulted from receding escarpments caused by weathering and erosion which are characteristic of arid regions.

During the Cretaceous Period, the present-day Colorado plateau existed as a large plain with only the borders being folded and faulted. Subsequent deformation produced folds such as the San Rafael Swell and Circle Cliffs. The plateau was covered more or less by Eocene deposits, such as the Wasatch Formation, and was of low relief with a well-developed exterior-drainage system (Dunbar, 1960). During the Pliocene, the Colorado plateau was uplifted, and major streams such as the Colorado, San Juan and Green were superimposed on the previous drainage system. As this uplift continued, more localized streams such as the Escalante, Fremont and Dirty Devil eroded through the geologic strata of the plateau. Concurrently, laccolithic intrusions built up the Henry, LaSal, Blue, and Carrizo mountains of southeastern Utah (Eardley, 1962).

At the present time the general appearance of the Henry Mountains area is one of stark contrasts. The precipitous peaks tower above extensive mid-level mesas and benchlands, which in turn dominate the low-lying arid plains and valleys below. The effects of water and wind erosion are present. Escarpments, such as those on the face of Wildcat Mesa, Pete Steele Bench and Tarantula Mesa, continually erode into alluvial fans, which support a sparse vegetation, resistant to drought and salinity. Red and white sandstone monoliths persist from ages of natural erosion. Sand deposits in the valleys and drainages attest to the erosive force of infrequent but violent desert storms.

The broad stream courses accommodate intermittent streams which are high in salinity. Small ranches and agricultural fields depend on limited streamflow or water which can be extracted from the stream beds to meet irrigation requirements.

C. Topography

Elevations on Capitol Reef west of the study area reach about 7,000 feet while Mt. Ellen in the Henry Mountains due east reaches over 11,000 feet. Elevations on the study area are near 6,000 feet. Sweetwater and Dugout Creeks, draining northwesterly from the Henry Mountains, are the principal drainage lines across the study area.

Elevations on the eight drill holes and the general configuration of the surface on the study area are shown on Figure 11.

Topographic details of the study area are shown on the Notom and Mt. Ellen quadrangles which are published by the United States Geological Survey in their 15 minute series (Figure 12). The study area crosses the shallow valley of Sweetwater Creek. To the west is Wildcat Mesa and to the east is Pete Steele Bench and Apple Brush Flat. The latter are

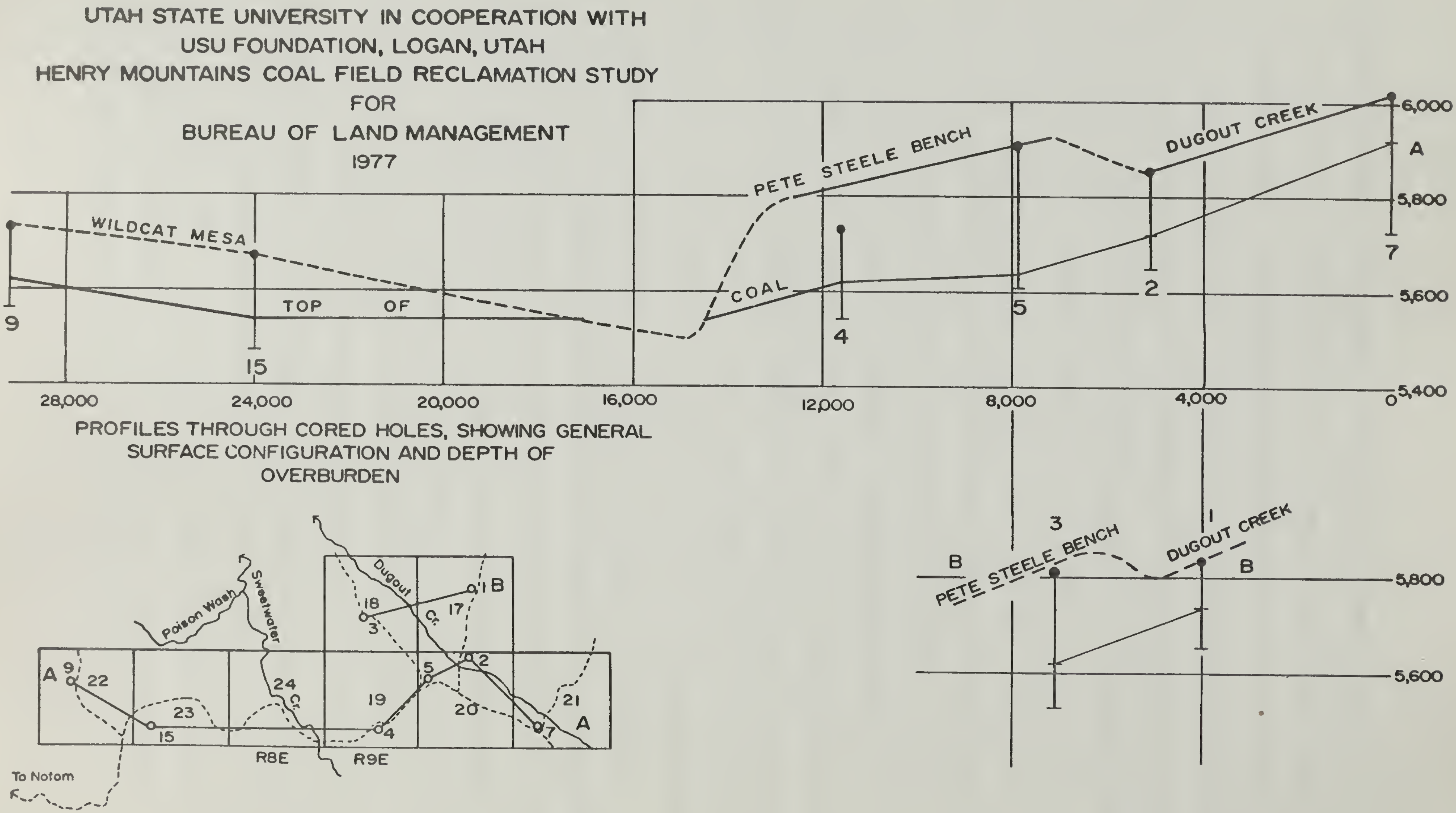


Figure 11. Elevations of the eight geologic core drill holes and their general topographic locations.

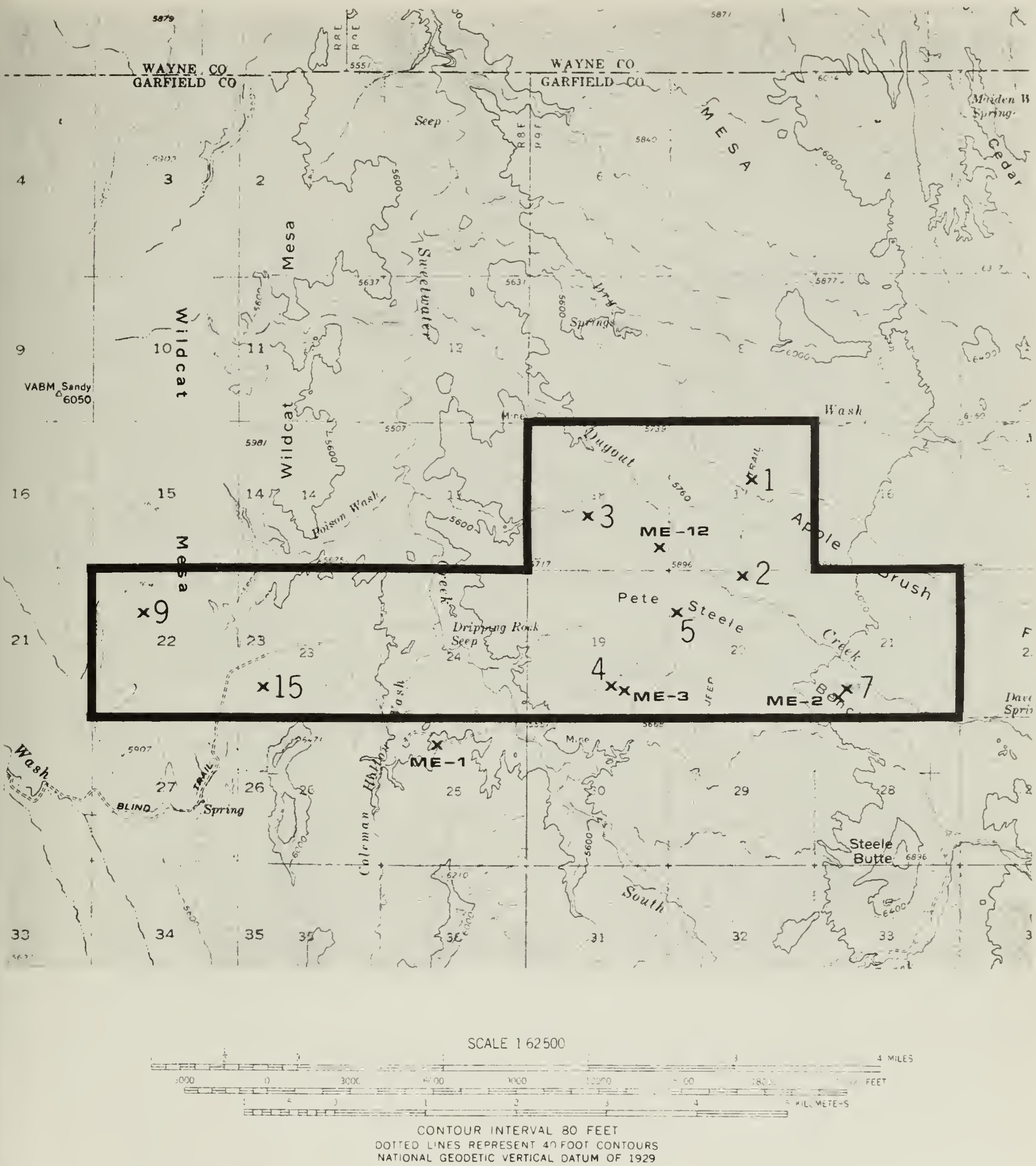


Figure 12. Topographic details of the study area as shown on the Notum and Mt. Ellen quadrangles.

Source: U.S. GEOLOGICAL SURVEY

pediment surfaces developed by the runoff from Mt. Ellen, on whose flank these graded surfaces lie. Between these two pediments, Dugout Creek flows northwesterly to Sweetwater Creek.

D. Geology

1. Regional Geology

Geologic maps of the general area have been provided by Hunt, et al, (1953), Hintze and Stokes (1964)and Doelling (1974). The definitive geologic report on the area is by Hunt, et. al., (1953). A part of the geologic map by Hintze and Stokes is most useful for the purpose of gaining a regional perspective of the coal field in relation to adjacent areas (Figure 13). A table listing the formations exposed in the Henry Mountains area is copied from Hunt, et. al., 1953 (Table 6). A geologic cross-section showing the Water Pocket fold and the Henry Mountains syncline is taken from the Fremont River Report, prepared by Utah Division of Water Resources (Figure 14).

Referring to the table of exposed formations, the Glen Canyon group of thick sandstones constitute the Capitol Reef and is crossed on Utah Highway 24 across the National park. At Notom junction, the highway is on the Carmel Formation. The unpaved road south follows the Entrada Sandstone, a weak formation that allows easy access south to the Sandy Ranch. Then the road turns east across the upturned edges of the outcrops of the Summerville and Morrison Formations, and the Dakota Sandstone. As the road trends southeasterly it traverses outcrops of the Tununk, Ferron and Blue Gate, climbing up Blind Spring Canyon on to Wildcat Mesa, created on the Emery Sandstone Tongue or member of the Mancos Shale Formation. At this point the road is now near the axis of the syncline or coal basin (Figure 14). This is the western end of the study area previously referred to in figures 7, 12 and 13.

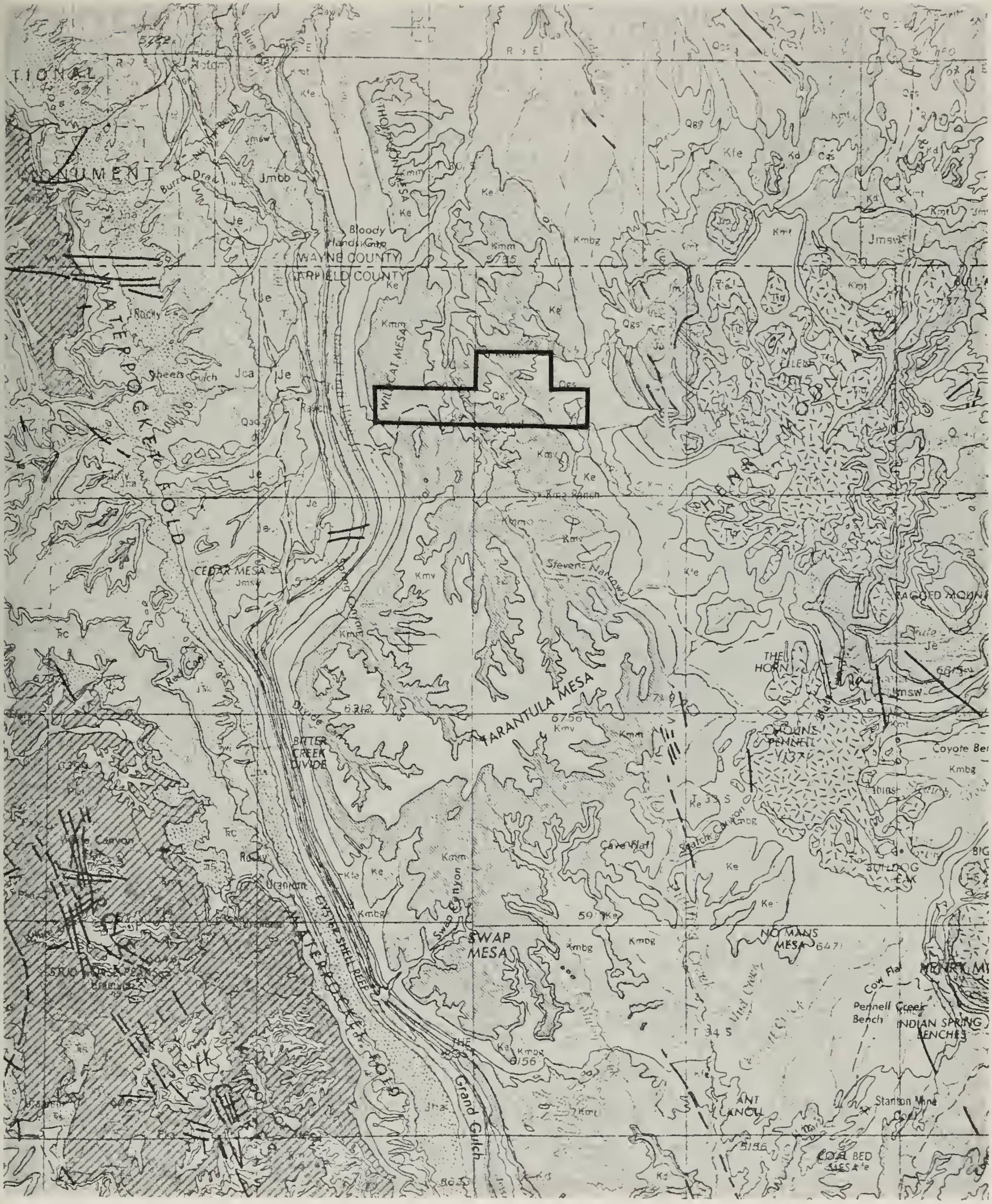


Figure 13. Surficial Geology of the Henry Mountains region. (Taken from Hintze and Stokes - 1964)

Table 6. Generalized section of sedimentary rocks exposed in the Henry Mountains region.

SYSTEM	SERIES	GROUP, FORMATION, AND MEMBER		THICKNESS (FEET)	LITHOLOGY
Quaternary.		Alluvium, colluvium, terrace gravel, and talus.			Sandy clay, sand and gravel in alluvium and alluvial fans; terrace gravel mostly on benches along streams; slope wash and talus.
		Unconformity			
Cretaccous.	Upper Cretaccous.	Mesaverde formation.		400	Cliff-forming sandstone containing thin interbeds of shale.
		Mancos shale.	Masuk member.	600 800	Lenticular sandstone, shale, carbonaceous shale, and shaly limestone. Mostly continental in origin, but some is marine.
			Emery sandstone member.	198 257	Lower 150 ft. is massive sandstone. Upper 50 ft. is lenticular sandstone, shale, carbonaceour shale, and coal.
			Blue Gate shale member.	1,500	Shale, blue-gray, marine.
			Ferron sandstone member.	150 300	Lenticular sandstone, shale, carbonaceous shale and coal, in upper 50-100 ft. Sandstone and thin beds of shale in lower 90-150 ft. Lower part grades eastward into Tununk shale member.
			Tununk shale member.	525 650	Shale, blue-gray, marine; numerous thin beds of bentonite.
		Dakota sandstone.		0 50	Cliff-forming conglomeratic sandstone; locally coal-bearing carbonaceous beds lie between two beds of sandstone.
		Unconformity			
Jurassic.	Upper Jurassic	Morrison formation.		500 600	Upper part mostly clay and shale, variegated, dominantly green-gray, maroon and mauve, lower part mostly sandstone and conglomerate, gray, very lenticular, massive, cross-bedded; some thin lenses of limestone; gypsum locally abundant at the base; jasper and other chart concretions common.
		Unconformity			
Jurassic.	Upper Jurassic	San Rafael group.	Summerville formation	40 250	Evenly bedded, reddish-brown sandstone and sandy shale; minor amounts of greenish-white sandstone, gypsum and limestone.
			Curtis formation.	0 175	Evenly bedded gray sandstone and shaly sandstone, glauconitic(?), numerous siliceous geodes and concretions at some places. Local thin basal conglomerate; marine.
			Unconformity		
			Entrada sandstone.	300 700	Thick-bedded and cross-bedded buff sandstone; weathers in rounded forms; thinner bedded earthy sandstone to north; forms flat sandy areas.
			Carmel formation.	100 626	Thin-bedded red sandstone, shaly sandstone and shale; thin limestone and, in northwest part of the area, thick beds of gypsum.
		Unconformity			
Jurassic(?).		Glen Canyon group.	Navajo sandstone.	515 815	Tan to light-gray, massive, cross-bedded sandstone; thin lenses of limestone.
			Kayenta formation.	240 320	Red sandstone and shaly sandstone, well-bedded; some cross bedding; minor amounts of red shale and green clay.
			Wingate sandstone.	270 380	Red and buff, cross-bedded sandstone; cliff-maker.
		Unconformity			
Triassic.	Upper Triassic.	Chinle formation.		200 855	Variegated sandstone, shale, limestone, and conglomerate; well-bedded but lenticular and intertonguing.
		Shinarump conglomerate.		12 275	Cross-bedded, lenticular sandstone, conglomerate, variegated shale. Much silicified wood.
		Unconformity			
	Lower Triassic.	Moenkopi formation including Sinbad limestone member.		250 700	Red and buff sandstone and red shale; some limestone. Abundant ripple marks. Well-bedded. Massive conglomerate at base.
		Unconformity			
Permian.		Kaibab limestone.		0 100	White, buff, and light-gray limestone and limy sandstone containing siliccous concretions.
		Coconino sandstone.		600	White to buff, massive, cross-bedded sandstone. Base not exposed.

QUATERNARY

Qal Alluvium

TERTIARY

Tv Lava flows with some tuff beds
Tt Tuffaceous beds with some lava
Tfl Flagstaff limestone

CRETACEOUS

Ke Emery ss.
Kmbg Mancos Sh., Blue Gate mbr.
Kf Ferron ss.
Kmt Mancos Sh., Tununk mbr.

JURASSIC

Jm Morrison fm
Je Entrada ss.
Jca Carmel fm
Jn Navajo ss.
Jk Kayenta fm

TRIASSIC

TRw Wingate ss.
TRc Chinle fm.
TRm Moenkopi fm

PERMIAN

Pk Kaibab ls.
Pc Coconino ss.

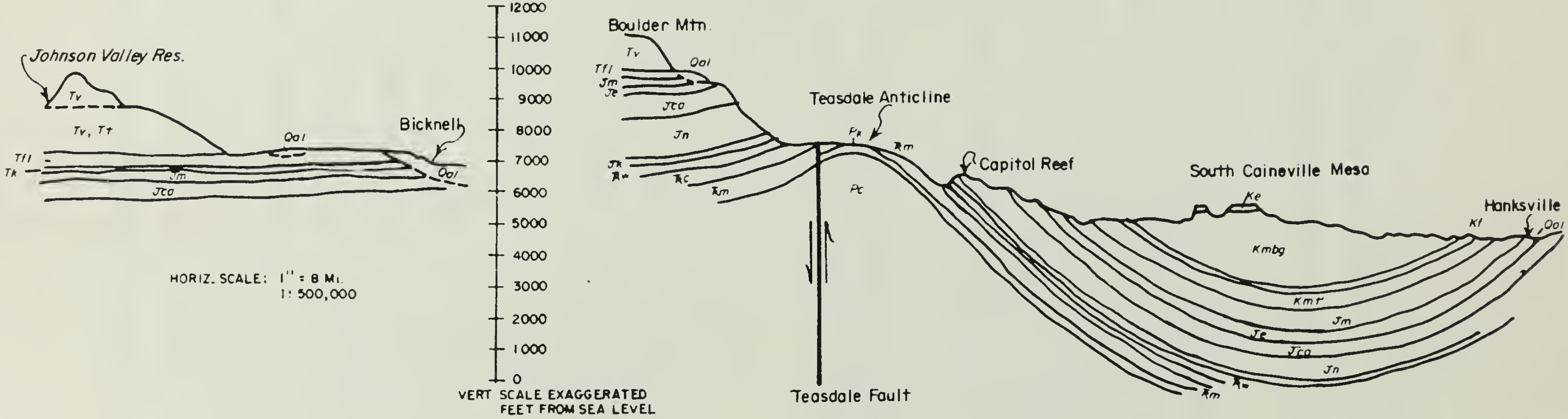


Figure 14. Geologic Sections-Fremont River Valley Area.
(Taken from Fremont River Study prepared by the Utah Division of Water Resources - 1975)

2. Geology of the Study Area

An aerial photograph provided for this study made possible the construction of a detailed map of the geology of most of the study area with the exception of Section 22, the westernmost section of Wildcat Mesa (Figure 15).

Drill holes are shown as solid black dots, with the number of the hole adjacent. At the left side of the map, Section 22 and Hole 9 which was drilled there are not shown, because the aerial photograph used as a base for the map did not extend that far. The vegetation estbalishment test plots designated A, B, C, D and E are shown as black squares. Plot F, in section 22, is off the map.

Figure 15 differs in local details from the map of Hintze and Stokes, which shows the outcrop of Masuk Shale (Kmm) much more extensive over the study area than it really is.

Two pediment surfaces are shown on Figure 15, an older and higher one called Pete Steele Bench, and a younger and lower one known as Apple Brush Flat. The gravels beneath these surfaces are from 0 to 20 feet thick, and are composed of roundstones of quartz diorite porphyry from the intrusive bodies of the Henry Mountains in a matrix of sand and finer material. Other surficial materials mapped are the floodplain sands and gravels along Dugout and Sweetwater creeks, and the Eolian silt and sand depostied in the southwestern corner from the gap created by Blind Trail Wash in the cuesta of Emery Sandstone.

The bedrock areas shown on the map cover Wildcat Mesa almost completely, as well as a wide area around the gravel-capped surfaces of the two pediment areas. The bedrock areas between the floodplains and

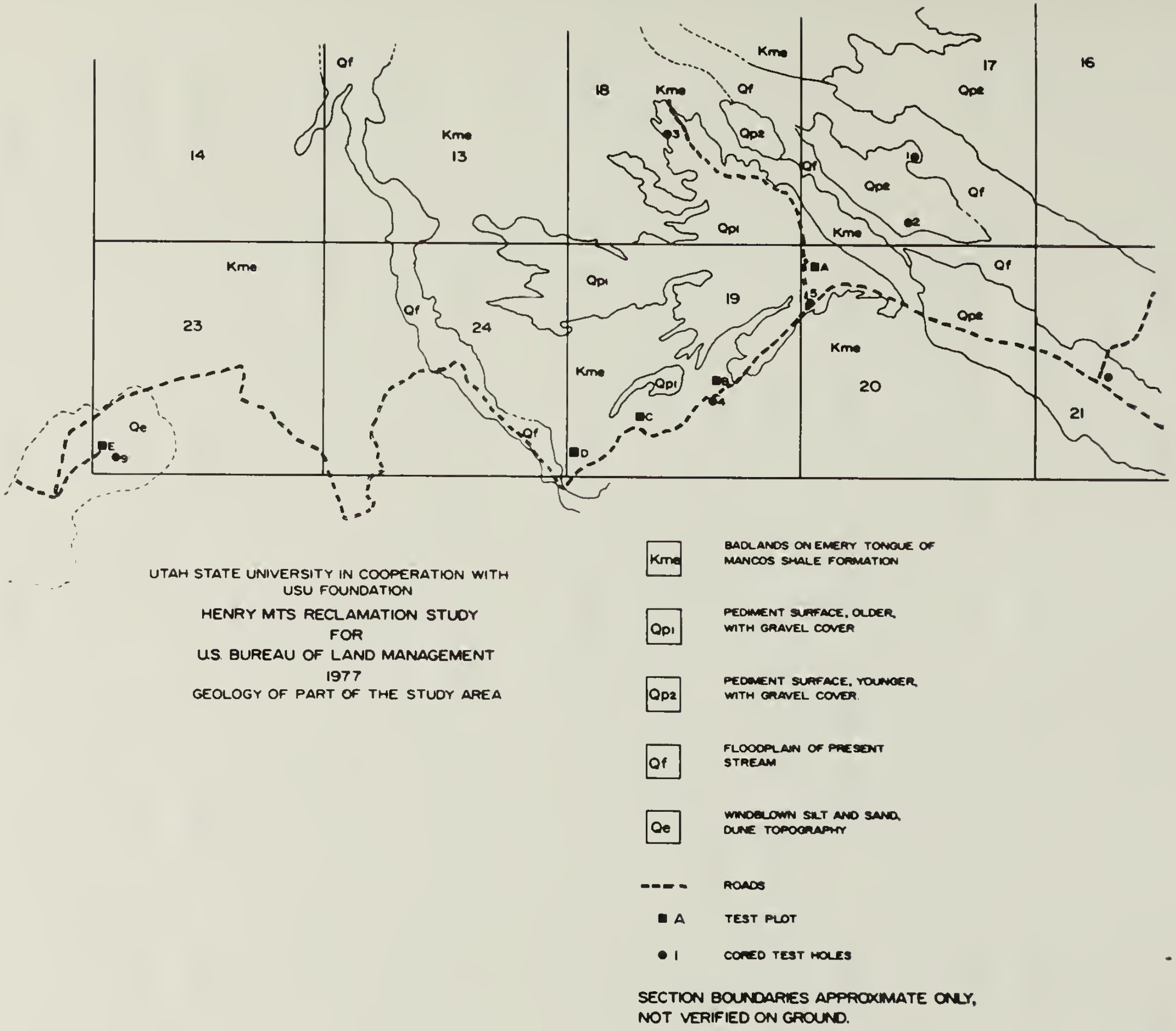


Figure 15. Surficial Geology of the Study area (with the exception of Section 22 and Plot F).

the pediment surfaces are escarpments, gentle in places, steeper in other places; these wind around the long salients that extend like fingers outward from the pediments, and follow the deep recesses cut into the edges of the pediments by the drainage lines. All exposed bedrock in the area is the Emery Sandstone Tongue of the Mancos Shale Formation. At the top of the escarpment, the exposed gravel cap wastes downward, strewing it with roundstones of quartz diorite porphyry. Where sandstone beds are exposed, the escarpment profile is steep but where mudstone and siltstone are at the surface, the profile is gentle.

Although the geologic drilling and coring in this study were limited to a 2-mile wide strip (refer to Figures 12, 15) stretching from Wildcat Mesa eastward to Pete Steele Bench and Apple Brush Flat, results of the study may be projected to areas beyond this strip, such as the lands to the north with the similar geology and topography. Results may also be considered to apply to all of Wildcat Mesa, with some confidence.

No attempts were made to measure the attitude of the Emery Sandstone in the study area. It was obvious that the dips were gentle, increasing somewhat at the east end as the Henry Mountains are approached, and increasing rather abruptly at the west end as the cuesta of Emery Sandstone, marking the edge of Wildcat Mesa. However, a measure can be obtained from the structural contour map (number 3) of Goode and Olson (1977), which shows contours on the top of the Navajo Sandstone. Scaling this map gives a dip of about 100 feet to the mile in a direction W S W from Hole 7 nearly to Hole 15. W S W of Hole 15, the reversed dip increases rapidly to the edge of Wildcat Mesa. The axis of the basin, which underlies the coal field, lies west of Sweetwater Creek about one and one-half miles to where the profile crosses it near Hole 15 (refer to figure 11). The center of the basin lies about 10 miles south of the profile, beneath Tarantula Mesa. No attempt was made to map small faults or minor flexures in the area. No faults were noticed where the escarpment was examined.

The coal that may be mined in this area is part of the Emery Sandstone Tongue of the Mancos Shale Formation, and the overburden is composed of the sandstones and shales of the Emery Tongue. The Masuk Shale member of the Mancos, which overlies the Emery Tongue, and all other rocks higher in the section, have been stripped away, except in one or two small areas where buttes of Masuk remain.

The Emery Sandstone is about 350 feet thick. It is divisible into a lower marine member and an upper terrestrial member where the coal is deposited. The average thickness of three measured sections of the lower member is 250 feet, and of the upper member 110 feet (Peterson and Ryder, 1975).

As background for an understanding of the Emery Sandstone, Hunt's description of this stratigraphic unit is included as follows:

> The Emery sandstone member of the Mancos shale was named by Spieker and Reeside (1925. p. 439) to include the sandy and carbonaccous beds about 1,000 ft below the top of the Mancos near the town of Emery in Castle Valley. Between the type locality and the Henry Mountains region the sandstone has been removed by erosion and it cannot be traced into this region, but the name as used in this report is applied to beds in the same stratigraphic position, which are lithologically like the type Emery and which overlie shale beds containing a marine fauna equivalent to the fauna in the beds beneath the type Emery. In Gilbert's report (1877b, p. 4) the name Bluegate sandstone was used.
>
> Lithology and thickness.--In the southern part of Castle Valley the Emery sandstone is about 800 ft thick but at the north end of the valley it thins to 100 ft and grades eastward into marine shale. In the Henry Mountains structural

basin the Emery is about 250 ft thick. It is largely restricted to the two or three townships in the deepest part of the basin. The lateral change eastward from the type locality indicates that the Emery, like the Ferron, probably never did extend far east of the Henry Mountains.

The Emery closely resembles the Ferron in consisting of a thick basal sandstone that overlies interbedded sandstone and marine shale and is overlain by carbonaceous and coal-bearing deposits. No important lateral changes in gross lithology or thickness were observed in the region and the following stratigraphic section is representative:

Section of Emery sandstone member, east side of Bullfrog Creek, half a mile below Cave Camp

		Feet
Top	Sandstone, 66 ft thick at base of Masuk member.	
1.	Shale, carbonaceous, with thin streaks of coal	19
2.	Sandstone, thin-bedded	2
3.	Shale, carbonaceous and sandy	5
4.	Coal	1
5.	Coal, shaly	2
6.	Coal	6
7.	Shale, carbonaceous and sandy	7
8.	Sandstone, thin-bedded	6
9.	Shale, carbonaceous	6
10.	Sandstone, massive; top 10 ft thinly bedded	78
11.	Sandstone, massive in beds 5 to 10 ft thick separated by shale in beds 2 to 3 ft thick	100
	Total thickness of Emery sandstone member	
	Base. Interbedded sandstone and shale at top of Blue Gate shale member.	232

Other measured sections show thicknesses ranging from 198 to 257 ft but probably a considerable part of the variation in thickness is due to inconsistency in selecting a base in the transition zone that underlies the member. Lateral changes such as were observed in the Ferron, were not found in the Emery sandstone member, probably because of the limited area covered by the Emery.

A moderately thick, massive sandstone generally is present at the top of the Emery member. This sandstone, which is regarded as the base of the Masuk member, is analogous to the lenticular sandstone at the top of the Ferron. It rests on the carbonaceous shale beds with sharp erosional unconformity but locally it has the form of a channel deposit and extends many feet into the underlying beds. An excellent coal bed at the top of the Emery at South Creek is cut off by this sandstone a mile south of the creek and a little farther south a considerable part of the carbonaceous beds in the upper part of the Emery is cut out also. The base of the sandstone rises again to the south and lenticular sandy carbonaceous shale and coaly beds reappear in the vicinity of Stephens Narrows.

Most of the carbonaceous beds are brown, sandy, and irregularly lenticular. Sandstone layers interbedded with the carbonaceous shale are fine-grained or coarse-grained and commonly contain more or less carbonaceous material.

The thick massive sandstone underlying the carbonaceous beds is light yellor or light gray, fine-grained, and evenly bedded in horizontal layers 2 to 10 ft thick. The layers are cross-bedded and locally contain concretions a few inches in diameter and cemented by iron oxide. The massive sandstone invariably forms a prominent scarp.

Sandstone interbedded with shale beneath the massive sandstone is also fine-grained, laminated, or platy and indistinctly cross-bedded. These beds become increasingly shaly downward where they grade into the Blue Gate shale member.

Physiographic expression.--Topographically the outcrop of the Emery sandstone member resembles that of the Ferron. An escarpment formed by the sandstone faces of the valley of the Blue Gate shale member and where dips are low the back side of the escarpment as a long dip slope. This escarpment is much higher than that formed by the Ferron. Outliers of the Emery form large mesas, like those at Caineville.

Mode of deposition.--the Emery was deposited over the Blue Gate shale member in the same as the Ferron was deposited over the Tununk shale member, by the sea being crowded eastward when the rate of deposition exceeded the rate of subsidence in this part of the geosyncline.

3. Surface Section

Before the coring began it seemed desirable to learn, if possible, what might be expected in the cores. A field study was undertaken to measure and sample a surface exposure of the Emery Sandstone member above the coal beds. An obvious location was the ridge just north of the road to the top of Pete Steele Bench in S W 1/4 sec. 19 T 31 S R 9 E (Figure 11). The section began on the exposed coal beds; two other convenient locations adjacent to the road as it climbed Pete Steele Vench were sampled. Later, parts of these sections were selected to be graded and prepared for test plots (labelled on Figure 15 as plots D, C, and B). Table 7 gives a description of the surface section. Eight samples were taken on the surface section, which were analyzed for particle size (Table 8).

4. Lithology of cores

One hundred percent recovery was achieved in taking the overburden cores. Minor loss occurred in some samples from the coal beds. The coal samples, desired by the United States Geological Survey, were taken in the field by their representatives. The remainder of the cores were examined to describe the overburden.

The examination was megascopic, using a land lens. Nine different categories or types of bedrock were distinguished as representative of all parts of all cores, except the coal beds. Coal and regolith complete the logs. The percentage of types in each hole was computed (Table 9).

Of the eight rock types recognized in the cores, those which are largely sandstone with minor amounts of organic matter or claystone make up 75% of the cores. The three types composed of fines, silt and clay make up only 15%.

The logs of the holes have been plotted on a relative scale in Figure 16 and in Appendix A. They have been projected on an east-west line through the study area, with the intervening distances approximate. Altitude and total depth of the holes are shown together with the location and thickness of the coal beds. The rock types in the cores are shown only in the general categories of regolith, mostly sandstone, mostly claystone

Table 7 Description of surface section of Pete Steele Bench escarpment as measured in two segments north of the road in SW 1/4 Sec. 19 (T 31 S R 9 E). Measurements by handlevel. Section starts on top of prominent white sandstone ledge in coal section. For particle size analysis of surface samples, see the following table.

UNIT 1	FEET
Sandstone, friable, yellowish, thin seams black with organic material; weathers to smooth slopes with pimply surface (Lab No. 94, Silty clay loam).	6
UNIT 2	
Medium and fine-grained sandstone, buff when wet; weathers to light gray slopes generally smooth but with pimply surfaces; concretions with gypsum crystals (Lab No. 95 Sand Loam) (Field plot D on this unit).	34
UNIT 3	
Same as Unit 2. Top of sandstone changes to darker colors.	17
UNIT 4	
Generally dark gray blocky gypsiferous shale; slopes darker gray, with shrinkage patterns. (Lab Nos. 96, 97, 98, Silt clay, clay and clay). (Field plot C on this unit).	31
UNIT 5	
Generally massive buff sandstone, torrential bedding, coarse to fine-grained, poorly sorted, shale intercalated. Samples low, middle and high in section. (Lab. Nos. 99, 100, 101, Loam Sand, Sand, Loam, Loam Sand) (Field plot B on this unit).	112
TOTAL THICKNESS	200

Table 8. Particle size analysis of samples collected on surface section. Determinations were made in USU soils laboratory.

		Hydrometer				Cumulative As received SIEVES (%) retained					
Lab No.	Coll. No.	% Sand	% Silt	% Clay	Texture	1 1/2	1	3/4	3/8	#4	#10
94	1	49	28	23	SiltClLoam	0	0	0	0	0	0
95	2	63	21	16	Sand Loam	0	0	0	0	0	0
96	4	10	44	46	Silt Clay	0	0	5	31	70	86
97	4+	16	36	48	Clay	0	0	0	0	0	3
98	4++	7	39	54	Clay	34	44	56	77	90	96
99	5 low	83	11	6	Loam Sand	0	0	0	0	0	0
100	5 mid	79	11	10	Sand Loam	0	0	0	0	0	0
101	5 high	79	15	6	Loam Sand	0	0	0	0	0	0

		Wet sieves of ground sample				
Lab No.	Coll. No.	2.1(mm)	1-.5(mm)	.5-.25(mm)	.25-.1(mm)	1.-.05(mm)
94	1	.2	.5	3.4	37.6	7
95	2	.4	.7	1.5	42.5	18
96	4	.3	.8	.6	1.2	7
97	4+	.2	.2	.3	1.0	14
98	4++	1.0	1.0	.6	1.4	3
99	5 low	15.1	11.9	6.1	36.4	13
100	5 mid	5.1	16.3	7.6	43.0	7
101	5 high	.1	.1	.8	61.0	17

Table 9. Lithology of geologic cores according to percentage of rock types in cores. Order of location is from west to east at study site.

ROCK TYPES	CORE 15	CORE 3	CORE 4	CORE 5	CORE 2	CORE 1	CORE 7	CORE 9	AVERAGE
1. Buff Sandstone	2	7	5	0	0	16	0	10	5
2. Buff Sandstone with organic material	0	0	0	11	0	0	10	18	5
3. Buff Sandstone with Claystone	13	0	0	14	8	12	0	25	9
4. Gray Sandstone	19	9	15	11	20	5	18	0	12
5. Gray Sandstone with Organic Material	6	13	16	31	19	19	2	7	14
6. Gray Sandstone With Claystone	15	40	43	13	26	19	54	24	29
7. Shale and/or Claystone	4	5	5	6	3	0	0	0	3
8. Siltstone	8	1	0	1	1	5	0	0	2
9. Mudstone or Claystone-Siltstone	18	16	8	2	11	14	9	5	10
10. Coal	12	5	6	5	6	4	2	8	6
11. Gravel or other Regolith	3	4	2	6	6	6	5	3	4

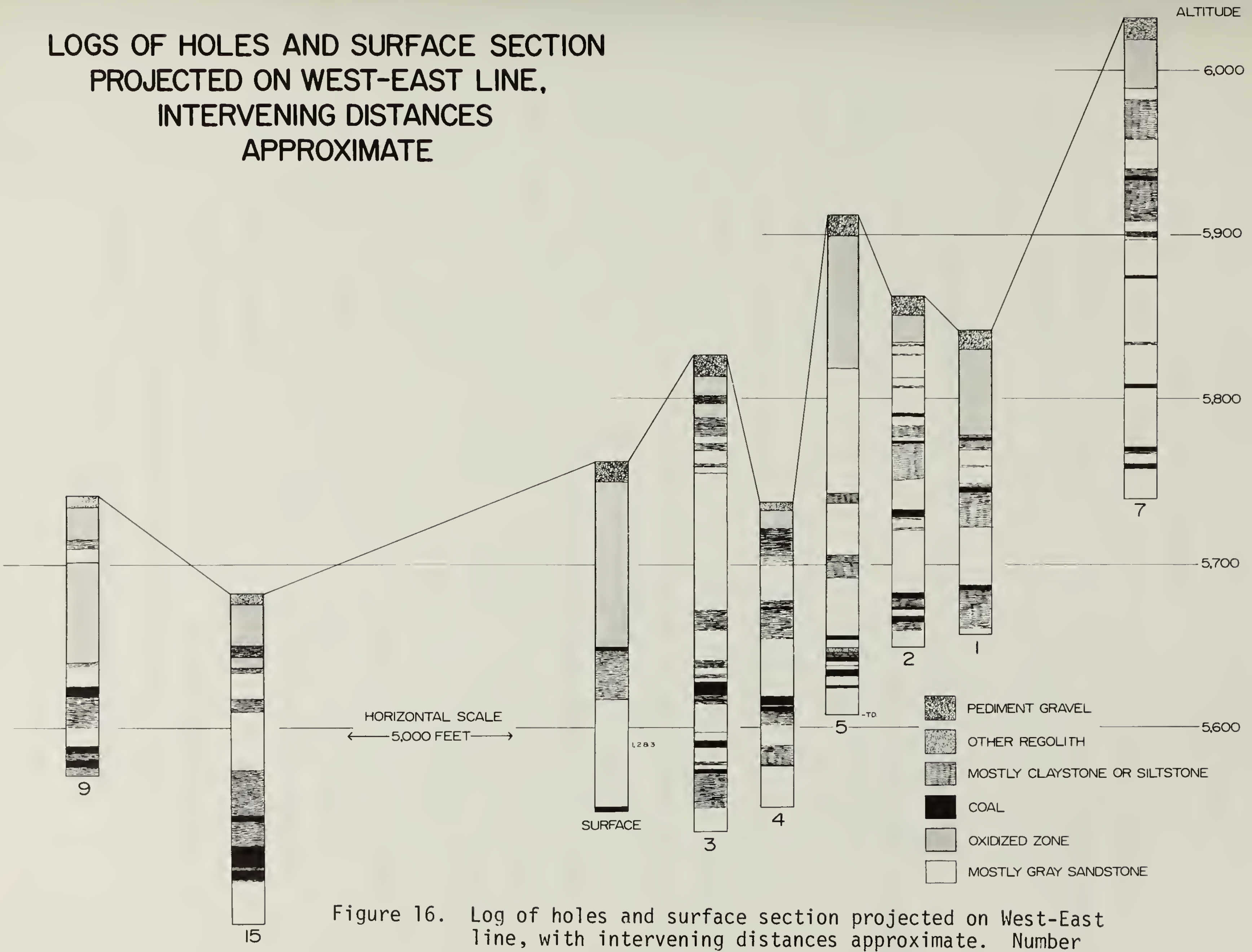


Figure 16. Log of holes and surface section projected on West-East line, with intervening distances approximate. Number at base of log indicates the core number assigned by the USGS.

or siltstone, and oxidized zone. The section measured and sampled on the surface is also included in the diagram.

The sediments represented in the overburden were transported on a gentle gradient that permitted the movement of fine and medium-sized sand only. No particles as large as 1.0 mm in diameter were observed in the samples.

Interpretation of the cores suggest a delta at or near sea-level where the distributaries of a river originating in the Upper Cretaceous Mountains of central Utah, to the west, carried mostly fine sand and finer suspended sediments eastward to the open sea.

Coastal swamps between the distributaries supported forests, beneath which the organic materials of the coal bed accumulated. Behind the low natural levees of fine sand and adjacent to the active channels, slack water stood, and silt and clay settled from the water until the water was shallow enough to permit plants to become established, which began accumulation of organic material. Slow sinking of the delta under the weight of the arriving sediments allowed the accumulation to continue in places until it reached a thickness which, under later compaction, would produce as much as 20 feet of coal. The swamp and lagunal areas sedimented at a slower rate than the active channels, and sooner or later became targets of the distributaries, compelled always to flow down the steepest gradient available. Then the swamp area was torn up -- the clay-blebs redeposited with sand in intraformational conglomerates, the organic matter mixed with the sand, and the clay and silt of the erstwhile swamp replaced in the succession by sand.

The cycle of deposits that represents the appearance and destruction of a lagoon or slackwater area is repeated at numerous positions in the cores. Sandstone grades upward into siltstone, then into claystone, then into carbonaceous shale, and then into coal. The coal is topped by a thin intraformational conglomerate of coal fragments and sandstone, representing the arrival across the buried lagoon of an active stream channel. The cycle is, of course, not always carried to completion. It may be interrupted at any stage and set back. In places thin laminae of organic matter accumulated in the sand; in other places, laminae of clay accumulated when currents slackened or disappeared for brief intervals.

Detailed descriptions of the cores of the eight holes are shown on geologic logs (Appendix A). Each log documents the hole number, its location, the ground elevation, and the total hole depth. The eleven categories to which the rock types were assigned are plotted on a graphic log adjacent the descriptions of the contents of each core. Three types of buff sandstone and three types of gray sandstone are distinguished, depending on the presence or absence of claystone or organic material. When the sandstone is described as containing both claystone and organic material, the presence of claystone is given precedence over the presence of organic matter. Also, since the descriptions are generalized over some sections of the core, it was possible to select samples for greenhouse study that represent variations of the general category but did not match exactly the graphic pattern opposite the position of sample selection. For example, sections of the log illustrated by the pattern for category 9 claystone-siltstone could furnish a sample of category 7, claystone and a sample of category 8, siltstone. Similarly a second of the log illustrated with the pattern for category 3, buff sandstone with claystone, could furnish a sample for category, buff sandstone, and for category 7, claystone.

5. Hydrogeology

Originally, all the sediments that make up the overburden were gray in color. Penetration of surface water on the outcrops with oxygen and to an extent, everywhere, has oxidized iron in the sediments, producing buff colors.

Water was reported by the driller in 6 of the 8 holes. There was no opportunity to determine the persistence or amount of this water because the holes had to be filled and cemented before the rig left the site. Considering the limited annual precipitation and high rate of evapotranspiration, the water yield is probably very small, only a fraction of an inch, and recharge to the possible ground-water reservoirs is very small. It seems unlikely to expect a general saturation zone beneath the study area in the Emery Sandstone. An exception might be a band beneath the courses of Dugout Creek and Sweetwater Creek, which are small perennial streams.

Ground-water may not present any problems in open-pit mining to the west of Sweetwater Creek, and little or no problem on the east side, provided that drainage lines from Mt. Ellen, including Dugout Creek, are directed from the pit.

There appears to be no evidence to contradict the final appraisal of Goode and Olson (July, 1977) that the Navajo Sandstone beneath the study area is probably saturated with water under artesian pressure. A water supply for rehabilitation might be obtained from a well or wells in the vicinity of Wildcat Mesa in areas of more likely recharge. Its quality is of concern, but might well be usable for revegetation programs involving salt-tolerant plant species.

In the Colorado Plateau province, except for the deep Grand Canyon in northern Arizona and the high plateaus in central Utah, the succession of strata is almost entirely sandstones and shales, with few or no carbonate units. The sandstones are the aquifers.

Beneath a possible well site along Sweetwater Creek in the study area, the downward succession of stratigraphic units would be:

Emery Sandstone Tongue, lower member
Blue Gate Shale
Ferron Sandstone Tongue
Tununk Shale
Dakota Sandstone
Shale Member of Morrison Formation
Sandstone Member of Morrison Formation
Summerville Formation
Entrada Sandstone
Carmel Formation
Navajo Sandstone
Kayenta Formation
Wingate Sandstone

Of these seven sandstones the Navajo is generally recognized as the best potential aquifer because of its thickness, better sorting, and hence highest porosity. This conclusion is again supported by Goode and Olsen (1977) in their assessment of the water resources of the Henry Mountains coal field.

The lower Emery and Ferron sandstones outcrop throughout the study area on the faces of escarpments where recharge opportunities are small. The Dakota and Morrison sandstones are relatively thin with limited recharge opportunities in the area being considered. The Entrada Sandstone in this general area is in its so-called red earthy facies, with a large proportion of fines, and hence low porosity. Water furnished by it tends to be of low quality (Goode and Olson, 1977).

In their final appraisal of the water resources of the area Goode and Olson report that the Navajo Sandstone beneath the study area is probably saturated with water under artesian pressure. If a well were to be located along Sweetwater Creek or Poison Wash in the study area, at approximately 5500 feet, the top of the Navajo Sandstone beneath would be at an elevation of 1,000 feet, and the well 500 feet into the top of the Navajo would be 5,000 feet deep. Artesian pressure would cause the water to rise thousands of feet toward the surface. If the Navajo is not fractured, the coefficient of storage and transmissivity of a well would be small, but the well might yield 60-100 gallons per minute.

Recharge areas of significance for the Navajo Sandstone near the study area are to the west and northwest, where perennial streams drain from the high plateaus of Boulder and Thousand Lake Mountains and cross the Navajo outcrop in Capitol Reef National Park. Presumably the Navajo sandstone formation is full from the crossings of Oak Creek, Pleasant Creek and the Fremont River, since they have had ages to fill the aquifer to its capacity. If much water were pumped from the Navajo in the study area, additional recharge would finally be induced from these streams. The time of such induction would depend upon the transmissivity of the aquifer and the quantity of water pumped. For the several hundred gallons per minute required for rehabilitation and operation of the mine, the time might be very long indeed.

The quality of water to expect from a well along Sweetwater Creek is questionable, since the quality of water found in the Navajo Sandstone varies from a few hundred parts per million to a few thousand parts per million to tens of thousands parts per million (Goode and Olson, 1977; Feltis, 1966). Near outcrop areas where recharge is rapid, the quality may be good; far down from the outcrop where the water has been confined for ages, it would be very poor. The study area appears to present an intermediate situation. The question of the quantity and quality of water that may be obtained here should be settled by drilling a test well, as soon as practicable.

6. Chemical Analyses of Geologic Core Samples

A representative 8-pound sample was taken from each lithotype (see Table 9) as it appeared in a geologic core. Inasmuch as lithotypes reoccur in the geologic cores, it was possible to take from one to three replicates of a lithotype from each case. At the time each sample was obtained the depth location was recorded. Coal and regolith were not sampled.

The reason for classifying core samples according to lithotypes, rather than by depth was to aid in interpreting data. The lithotypes are easy to identify and are more useful in classifying data than is depth alone, because the order of layering and thickness of geologic strata can vary considerably within horizontal distances of less than a mile.

Core samples were mechanically crushed and divided into two portions, one for bioassay and the other for chemical analysis. Chemical analyses were performed on the less than 2 mm diameter particle size fraction by the Utah State University Soil, Plant and Water Analysis Laboratory. Methods of the U. S. Salinity Laboratory (USDA, Agr. Res. Serv., 1954) were used to analyze for EC_e (procedure 4b), pH (procedure 21a), Boron (Procedure 73b, saturation extract), soluble ions (Na, K, Ca, Ms, SO_4, CI, and HCO_3 in 1:1 extract; procedures 7, 12, 13, 14a) and cation exchange capacity (procedure 19). Methods of Lindsey and Norwell (1969) were used to analyze for iron, zinc, copper, manganese. Molybdenum and lead were analyzed, using methods of Chapman and Pratt (1961; procedure 18-3). Black's (1965) procedures for analyzing lime (procedure 91-7), nitrate (procedure 84-5.3) and total nitrogen (procedure 83-3) were used. Phosphorus and potassium were analyzed according to Black (1965), as modified by Watanabe and Olsen (1965).

Results of the chemical analyses appear in Table 10. The mean value and range of each chemical characteristic are listed by lithotype. Values for the 6 surface samples are also shown for comparison, but are discussed in the section on soils. Generally all the lithotypes were extremely deficient in available nitrogen and phosphorus. Only 3 core samples had P contents greater than 2 ppm, and most contained less than 1 ppm P. Ten core samples contained more than 2 ppm nitrate, whereas most had less than 1 ppm. Potassium contents averaged higher in those lithotypes with greater amounts of clay and silt.

The pH values were, in general, near 8.0, but ranged as low as 3.7 and as high as 8.8. Electrical conductivities of saturation

Table 10. Chemical analyses of drill core samples and soil surface samples from field sites.
Page 1

	pH			EC_e (mmho/cm)			B (ppm)			Fe (ppm)		
[1]Lithotype	$\overline{X}$	Low	High	$\overline{X}$	Low	High	$\overline{X}$	Low	High	$\overline{X}$	Low	High
1	8.0	7.3	8.5	2.1	0.3	10.5	0.2	<0.1	0.4	16.6	4.3	32.0
2	7.9	7.2	8.6	2.0	0.4	8.8	0.1	<0.1	0.4	19.9	7.8	37.0
3	7.9	7.3	8.3	2.5	0.6	7.8	0.1	<0.1	0.2	19.0	10.0	43.0
4	7.7	4.0	8.4	1.0	0.4	3.6	0.1	<0.1	0.2	32.3	15.0	127.0
5	7.0	3.7	7.9	2.0	0.5	12.5	0.5	<0.1	1.6	61.3	31.0	178.0
6	7.7	6.0	8.3	1.4	0.8	3.2	0.1	<0.1	0.3	55.5	16.0	129.0
7	7.8	6.9	8.6	1.6	0.8	3.4	0.3	<0.1	1.6	38.9	16.0	76.0
8	7.8	5.9	8.8	1.7	0.9	4.5	0.7	<0.1	3.3	42.1	13.0	82.0
9	7.7	6.3	8.5	1.9	0.9	5.4	0.4	<0.1	1.9	44.7	15.0	109.0
[1]Soil Surface												
A Soil	8.1			0.8			0.1			3.2		
B Outcrop	8.0			0.5			<0.1			4.2		
C Outcrop	4.7			9.5			<0.1			7.4		
D Outcrop	8.1			9.5			<0.1			6.2		
E Soil	8.2			0.5			0.5			5.2		
F Soil	8.0			4.0			1.4			4.2		

Table 10. Chemical analyses of drill core samples and soil surface samples from field sites
Cont. Page 2

	Cu (ppm)			Mn (ppm)			Zn (ppm)			P (ppm)		
[1]Lithotype	$\overline{X}$	Low	High	$\overline{X}$	Low	High	$\overline{X}$	Low	High	$\overline{X}$	Low	High
1	0.5	0.3	1.0	7.4	0.8	24.0	0.5	0.3	0.9	0.7	<0.1	8.8
2	1.0	0.4	2.7	8.0	2.2	16.0	1.4	0.3	12.0	0.2	<0.1	0.5
3	1.5	0.7	3.9	8.2	2.7	17.0	0.7	0.3	1.2	0.2	<0.1	0.6
4	0.5	0.3	1.5	3.3	1.0	7.5	1.0	0.2	11.0	0.2	<0.1	0.6
5	0.8	0.4	2.9	6.8	3.0	19.0	1.0	0.3	5.9	1.2	<0.1	20.0
6	1.0	0.5	1.4	6.1	1.1	15.0	1.0	0.4	1.6	0.3	<0.1	0.8
7	3.6	1.7	5.7	2.4	0.4	7.9	3.2	0.8	6.5	0.3	<0.1	3.2
8	3.9	0.5	5.2	5.7	0.6	27.0	1.2	0.7	2.3	0.4	<0.1	0.7
9	2.3	1.1	4.9	5.2	0.4	27.0	1.7	0.7	4.9	0.5	0.1	1.3
[1]Soil Surface												
A Soil	0.8			5.1			0.7			11.0		
B Outcrop	0.4			3.6			0.6			1.7		
C Outcrop	5.0			1.4			12.0			2.3		
D Outcrop	0.4			3.2			1.0			<0.1		
E Soil	0.5			3.5			0.8			4.5		
F Soil	1.7			1.0			0.7			2.6		

Table 10. Chemical analyses of drill core samples and soil surface samples from field sites
Cont. Page 3

	K (ppm)			NO$_3$ (ppm)			Soluble ions (Me/100 g)								
							Na			K			Ca		
Lithotype	$\overline{X}$	Low	High	$\overline{X}$	Low	High	$\overline{X}$	Low	High	$\overline{X}$	Low	High	$\overline{X}$	Low	High
1	56.2	32	84	1.1	<0.1	4.6	7.1	1	60	1	1	1	2.0	1	6
2	65.1	41	112	1.0	0.1	4.0	5.2	1	47	1	1	1	2.8	1	24
3	103.0	64	233	2.2	<0.1	17.0	5.7	1	35	1	1	1	3.1	1	17
4	55.4	17	108	0.1	<0.1	0.2	1.7	1	6	1	1	1	1.9	1	3
5	66.7	37	120	0.2	0.1	0.4	2.2	1	8	1	1	1	3.9	1	12
6	156	72	193	0.3	0.1	0.6	4.7	1	7	1	1	1	2.1	1	6
7	248	141	>320	1.0	0.1	11.0	3.4	1	10	1	1	1	2.5	1	9
8	207	114	297	0.4	0.1	0.6	4.0	1	9	1	1	1	2.7	1	13
9	220	133	>320	0.3	0.2	1.0	3.4	1	15	1	1	1	4.5	1	29
oil Surface															
A Soil	>320			2.3			1			1			1		
B Outcrop	65			0.7			1			1			1		
C Outcrop	170			0.2			18			1			14		
D Outcrop	50			0.3			33			1			13		
E Soil	188			1.0			1			1			1		
F Soil	102			1.5			19			1			23		

Table 10. Chemical analyses of drill core samples and soil surface samples from field sites

Cont. Page 4

Soluble ions (Me-100 g)

	Mg			SO_4			CI			HCO_3			SAR		
^{1}Lithotype	$\overline{X}$	Low	High	$\overline{X}$	Low	High	$\overline{X}$	Low	High	$\overline{X}$	Low	High	$\overline{X}$	Low	High
1	3.1	1	8	9.6	1	70	1.1	1	2	1.5	1	2			
2	4.4	1	29	9.7	2	50	1.1	1	3	1.6	1	3			
3	6.5	1	38	11.4	1	46	1.1	1	2	1.9	1	3			
4	1.7	1	3	3.2	1	9	1	1	1	1.5	1	2			
5	4.3	1	26	7.8	1	45	1	1	1	2.4	1	6			
6	1.9	1	4	3.6	2	10	1	1	1	2.6	1	3			
7	2.2	1	7	4.6	1	14	1	1	1	2.4	2	4	2.9	0.6	10.0
8	2.0	1	9	5.3	1	26	1	1	1	2.8	1	5	3.4	0.8	6.4
9	3.5	1	26	6.7	1	51	1	1	1	2.6	1	4	2.1	0.4	9.0
oil Surface															
A Soil	1			1			1			2					
B Outcrop	1			1			1			1					
C Outcrop	74			103			1			1			2.7		
D Outcrop	8			53			1			1					
E Soil	1			1			1			1					
F Soil	2			46			1			1			5.4		

extracts ranged from 0.3 to 12.5 mmho/cm, but most values were about 1.0 to 2.0. Boron was usually less than 0.5 ppm. Only 7 samples had B contents greater than 1.0 ppm, and the highest value was 3.3 ppm.

Iron contents were highly variable, ranging from as low as 4.3 ppm to as high as 178 ppm. The extremely high values were associated with the low-pH samples. The more common Fe values were in the 20 to 50 ppm range. Copper contents ranged from 0.3 to 5.7 ppm. Higher copper contents were associated with higher clay or silt contents. Manganese and zinc contents were quite variable and not related to lithotype.

Total (perchloric acid digestible) molybdenum and lead contents were consistently less than 50 ppm and are not shown in the table. Percent lime and cation exchange capacities were determined for crushed drill core samples from Drill Hole 15 on Wildcat Mesa. Percent lime values ranged from 0.2 to 23.1 with an average of 8.1 cation exchange capacity (CEC) ranged from 0.8 to 26.0 me/100 g. The higher CEC values were associated with geologic materials of high clay contents.

7. Greenhouse Bioassay of Geologic Core Samples and Soils

The purpose of the greenhouse bioassay was to detect the presence of toxicities in the geologic overburden and soil samples. As stated in the chemical analysis section, core samples of each lithotype present (refer to Table 9) were sampled at 3 depths, wherever possible according to the presence of the lithotype, thus providing replication for the bioassay.

The second portion of each lithotype sample prepared according to the process described in the previous section was used in the greenhouse bioassay. To provide a direct comparison of plant responses on geologic materials, soils from six field sites were also sampled and treated as the crushed cores.

Nine hundred grams of crushed sample were placed in plastic cottage cheese cartons. Fifty grams of sample were removed from each pot and saved. Each pot received 90 ppm N as $Ca (NO_3)_2$ solution and 30 ppm P as $Na H_2PO_3$ solution. The samples were then watered with distilled water by weight to field moisture capacity (1/3 atm moisture percentage). Russian wildrye (see Appendix E for scientific names of plant species) seeds were planted on the moist soil surface, and the 50 grams of dry sample saved were used to cover the seeds. Russian wildrye, a non-native grass, was used in the bioassay because it is relatively easy to propagate from seed in the greenhouse and is a potentially useful species for rehabilitating arid sites.

After 3 days the potted samples were watered by weight to field moisture capacity. Thereafter, the soil surfaces were kept moist by periodic misting with a squirt bottle, along with daily watering by weight with distilled water to field moisture capacity, until germination occurred. After complete germination, the frequent surface moistening was discontinued and the seedlings were thinned to 5 per pot. Tops were harvested after 60 days, oven dried, and weighed.

Mean top yields of Russian wildrye on the nine lithotypes are shown in Table 11. Mean yields were not significantly different on buff sandstone, buff sandstone with organic matter, gray sandstone, or gray sandstone with organic matter. Highest mean yield occurred on claystone-siltstone followed by claystone, gray sandstone with clay, buff sandstone with clay, and siltstone. Growth in the greenhouse is not necessarily indicative of field performance, particularly under arid conditions. Differences in greenhouse plant growth on sandy versus clayey materials

Table 11. Top Yields of Russian Wildrye After 60 Days Growth in the Greenhouse on Crushed Drill Core Samples and Soils Surface Materials from the Henry Mountains Coal Field.

NUMBERS ASSIGNED IN TABLE 5	LITHOTYPE (AS SHOWN IN FIGURE 15)	TOP YIELD (mg)		NUMBER OF SAMPLES[2]
		MEAN[1]	RANGE	
1.	Buff Sandstone	536 d	209 - 850	17
2.	Buff Sandstone with Organic Matter	545 d	394 - 796	18
3.	Buff Sandstone with Clay	1036 bc	539 - 1493	21
4.	Gray Sandstone	632 d	0 - 898	23
5.	Gray Sandstone with Organic Matter	543 d	0 - 952	24
6.	Gray Sandstone with Clay	1126 bc	301 - 1541	22
7.	Claystone	1161 b	788 - 1561	20
8.	Siltstone	977 c	32 - 1868	15
9.	Claystone-Siltstone	1418 a	387 - 1825	21
AS LOCATED ON FIGURE 14	SOIL SURFACE (LOCATIONS SHOWN)			
A.	Sandy Loam Soil	590	544 - 631	3
B.	Crushed Sandstone Outcrop (Loamy Sand)	517	472 - 561	3
C.	Crushed Shale Outcrop (Silty Clay)	1112	1060 - 1146	3
D.	Crushed Sandstone Outcrop (Loamy Sand)	82	63 - 97	3
E.	Loamy Sand Soil	208	185 - 251	3
F.	Silty Clay Soil	825	813 - 836	3

[1] Mean value for the number of samples tested (column 3)
Means followed by the same letter do not differ significantly at the .05 level using Duncan's multiple range test.

[2] Number of samples is the total of 3 replicates of a lithotype sampled per drill core in the eight core drillings. Numbers less than 24 indicate that the lithotype did not repeat at least three times in all

are due primarily to differences in fertility and toxicity of the growth medium.

The main value of the greenhouse bioassay was to identify any lithotype with toxic properties. Only 3 of 181 core samples were highly toxic to Russian wildrye. The toxic samples were: 1) a siltstone taken at a depth of 157 feet, just below coal and containing carbonaceous material, from hole number 1 on Pete Steele Bench; 2) a sandstone with organic matter from the 38 foot depth of hole number 9 on Wildcat Mesa, and 3) a gray sandstone sample just below coal at a depth of 176 feet in hole number 15 on Wildcat Mesa. Two of the highly toxic samples had a pH of 4 or less, and one of these also had an EC_e of 12.5. The third toxic sample had a pH of 5.9, and a boron content of 3.3 ppm.

Statistical correlations between shoot yields and the various chemical data were run. Significant (.05 level) correlations were found with shoot yield and pH (Figure 17), EC_e (Figure 18), and boron (Figure 19). These chemical characteristics should be monitored throughout the mining and rehabilitation operation. Yields of Russian wildrye decreased when pH dropped below 7.0, when EC_e exceeded 4.0 mmho/ec, and when boron content exceeded 1.0 ppm.

E. Coal

It was not the responsibility of Utah State University to study or describe the coal resources, per se. However, some general observations on number and thickness of the coal beds encountered in the 8 holes is possible.

The United States Geological Survey took a total of 13 coal samples from the eight holes. A discussion of coal quality, prepared by Joe Hatch and Ronald Affolter, USGS Staff; is found in Appendix B. Presumably they sampled all beds of possible commercial value.

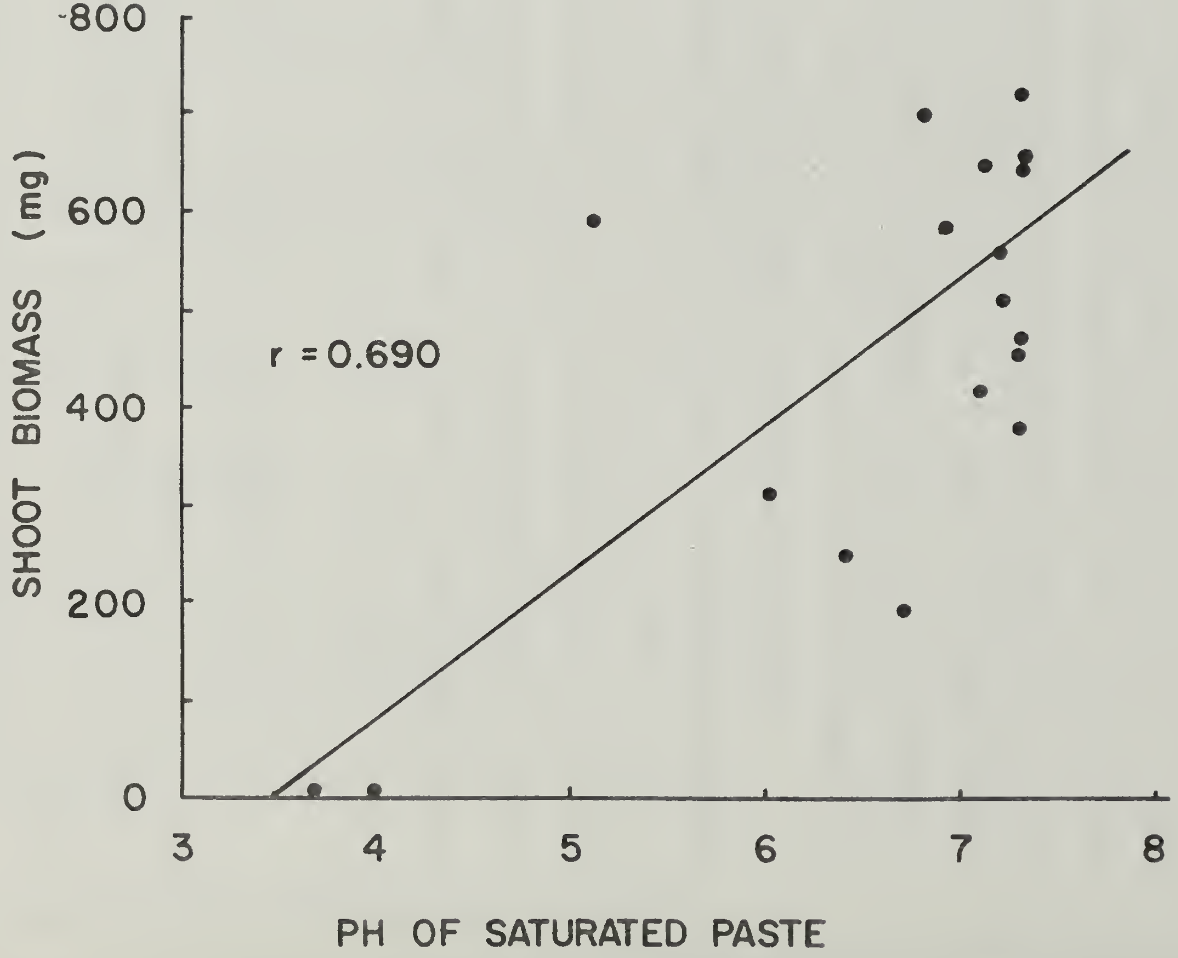


Figure 17. Correlation of biomass production to pH of Lithotype materials on which plants were grown.

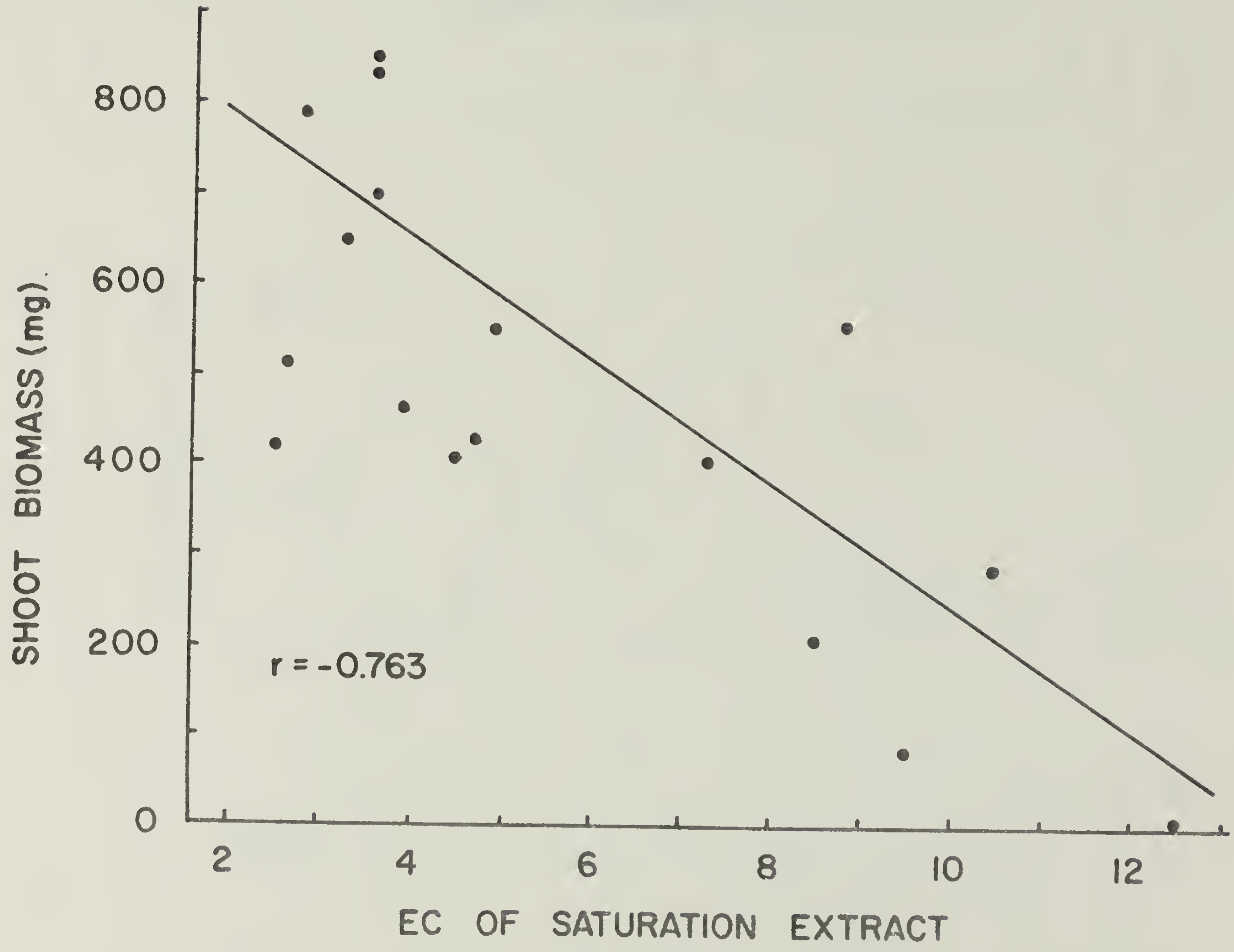


Figure 18. Correlation of biomass production to salinity (expressed as electrical conductivity, EC mmhos/cm) of lithotypes on which plants were grown.

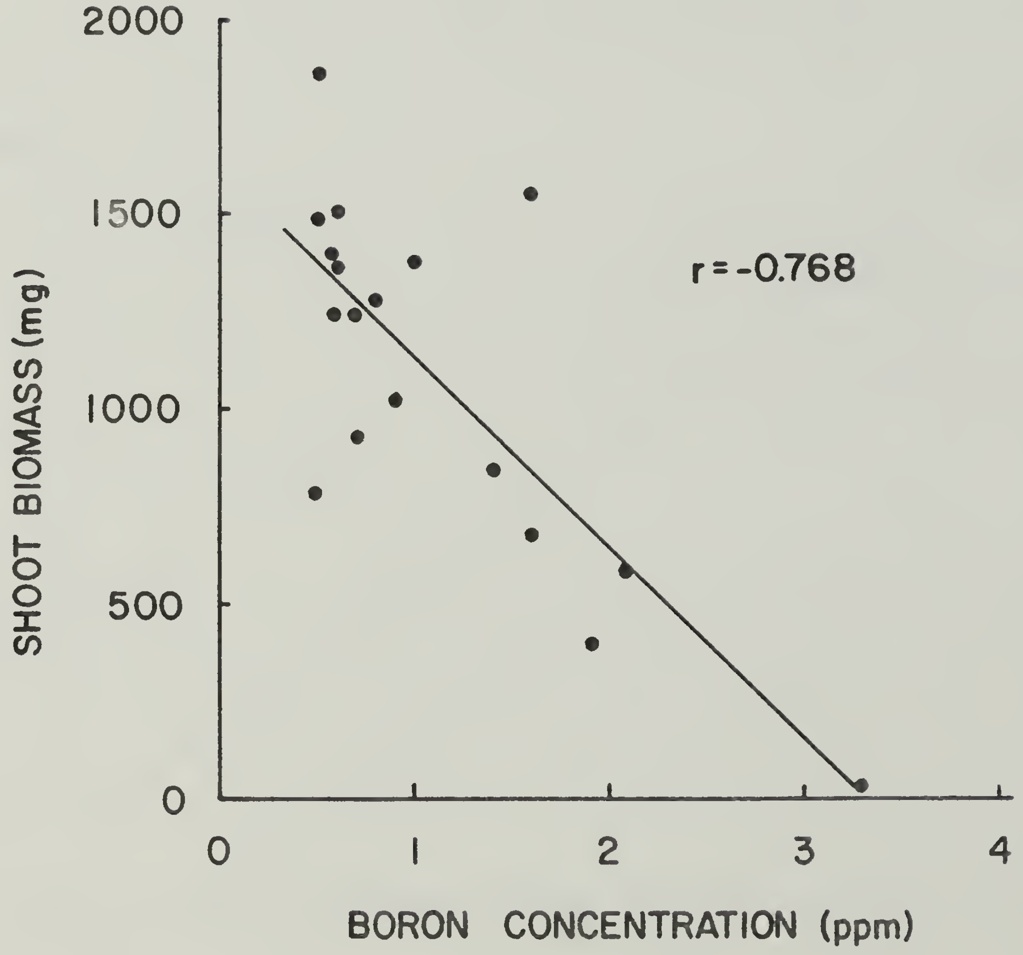


Figure 19. Correlation of biomass production to boron content of lithotype materials on which plants were grown.

Depth to the first sampled bed, the thicknesses of all sampled beds, and the total thicknesses of such beds in each hole are given in Table 12. Depth to the first sample may be considered the depth of overburden for that hole. This depth is greatest in Hole 5 (268 feet) and least in Hole 7 (96 feet), but there are fewer than 3 feet of coal in Hole 7 at that depth. Hole 5 has only 2 feet of core. In all other holes, the depth of overburden ranges from 115 to 199 feet. In sections 18 and 19, there are two coal beds with a total thickness near 8 feet. East of these sections there is only one bed, 2-3 feet thick. West of Sweetwater Creek, there are 3 beds with a total thickness of 13-15 feet.

The conventional way to show the thickness of the overburden would be an isopach map. But an attempt to create one from the limited data at hand did not appear to be worthwhile for the following reasons: 1) there were only eight holes drilled in an area of at least eight square miles, and 2) there is no definition of the mineable mineral bed for this area. The beds west of Sweetwater Creek appear thick enough to mine, as do those on the east side as far as Holes 3 and 4. East of holes 3 and 4, the beds are thin, and Hole 2, the highest coal bed noted by this study team, was not sampled by the United States Geological Survey; in Hole 7 a higher bed, recognized by us as the highest coal, did not meet the minimum requirements for thickness by the Geological Survey. No beds were sampled by the USGS for Hole 1 and 3. The zero isopach, marked by the outcrop of the coal beds about the mesa, has not been mapped. The contract did not call for such mapping.

Given these circumstances only a general statement can be made about the coal beds. The overburden varies in depths from zero to 200 feet in the location west of Hole 5. At Hole 5, the overburden of 268

Table 12. Depth to sampled coal and thickness of sampled beds

GEOLOGIC FEATURES	CORE HOLE							
	9	15	3	4	5	2	1	7
Depth to highest sample taken	115	151	199	118	268	132	NONE	96
Thickness of Sampled beds in order	6'0" 3'6" 4'0"	6'9" 3'10" 4'4"	5'10" 1'9"	5'5" 3'0"	2'0"	3'4"		2'9"
Total thickness of sampled beds	13'6"	14'11"	7'7"	8'5"	2'0"	3'4"		2'9"

feet covers 2-foot coal bed. On Apple Brush Flat and along Dugout Creek, the overburden depth may range from 100 to 200 foot over beds of any appreciable thickness. On Wildcat Mesa the overburden probably does not exceed 150 feet, except under the butte of Masuk Shale.

F. Soils

1. Soil Classification and Interpretation

Data on soils were provided by the USDA Soil Conservation Service (1977). Only soils in the immediate vicinity of the study site are included in this report. Further information on soils of the Henry Mountains coal field area can be obtained from the soil survey report.

A taxonomic classification of soils in the Henry Mountains Soil Survey appears in Table 13. A legend of soil mapping units is found in Table 14, and the soils maps of the Wildcat Mesa - Pete Steele Bench area are given in Figure 20. Analytical data for the major soil classifications are listed in Table 15.

a. Descriptions of soil units mapped are in Appendix C. These descriptions are taken from the USDA Soil Conservation Service (1977) report of the area.

b. Suitability of soil for use in rehabilitation. A general assessment and interpretation of the soils described in the Henry Mountains Resource Area soil survey is presented in Table 16. In addition to the general interpretations, several soil parameters related to land rehabilitation and plant growth are summarized in Table 17. These ratings are based on ecological and physiological tolerances of the native vegetation, on factors affecting erosion, and on factors affecting the quantities of soil available.

This system of suitability ratings was applied to the soils of the study area (Table 15). Soil depth (and hence volume available) and

Table 13. Classification of Soils and Map Symbols Used

Symbol	Family or higher taxonomic class
Ba	Loamy, mixed, (calcareous), mesic Lithic Ustic Torriorthents
Fa	Coarse-loamy, mixed, (calcareous), mesic Ustic Torriorthents
Ga	Clayey, mixed, (calcareous), mesic, shallow Typic Torriorthents
Ha	Coarse-loamy, mixed, (calcareous), mesic Ustic Torrifluvents
Ja	Fine-silty, mixed, (calcareous), mesic Ustic Torrifluvents
Na	Loamy-skeletal, mixed, mesic Ustochreptic Calciorthids
Ma	Coarse-loamy, mixed, mesic Ustochreptic Calciorthids
Pa	Loamy-skeletal, mixed, mesic Ustochreptic Calciorthids
Ra	Coarse-loamy, mixed, mesic Ustochreptic Calciorthids

Table 14. Soil Legend

Symbol	Soil Mapping Unit Name
BaD	Ba - Rock outcrop complex, 4 to 15 percent slopes Ba fine sandy loam, 4 to 15 percent slopes-40% Rock outcrop-35%
BbF	Rock outcrop - Ba complex, excessively rocky, Rock outcrop-70% Ba stony sandy loam, 15 to 40 percent slopes-25%
BB	Badland
RB	Badland - Rock outcrop complex, Badland-50% Rock outcrop-35%
FaB	Fa loamy fine sand, 2 to 4 percent slopes
GaD	Ga silty clay, 2 to 15 percent slopes
GaG	Ga gravelly silty clay, 30 to 60 percent slopes
HaB	Ha fine sandy loam, 2 to 4 percent slopes
HaC	Ha fine sandy loam, 4 to 8 percent slopes
JaA	Ja silt loam, 0 to 2 percent slopes
MaB	Ma very fine sandy loam, 2 to 4 percent slopes
NaB	Na fine sandy loam, 2 to 4 percent slopes
PaD	Pa gravelly very fine sandy loam, 4 to 15 percent slopes
RaF	Ra very cobbly very fine sandy loam, 15 to 40 percent slopes
RR	Rock outcrop
UT	Ustic Torriorthents, nearly level

Figure 20a. Soil survey map of study area. Henry Mountains Resource area. (Sheet 1 of 2)

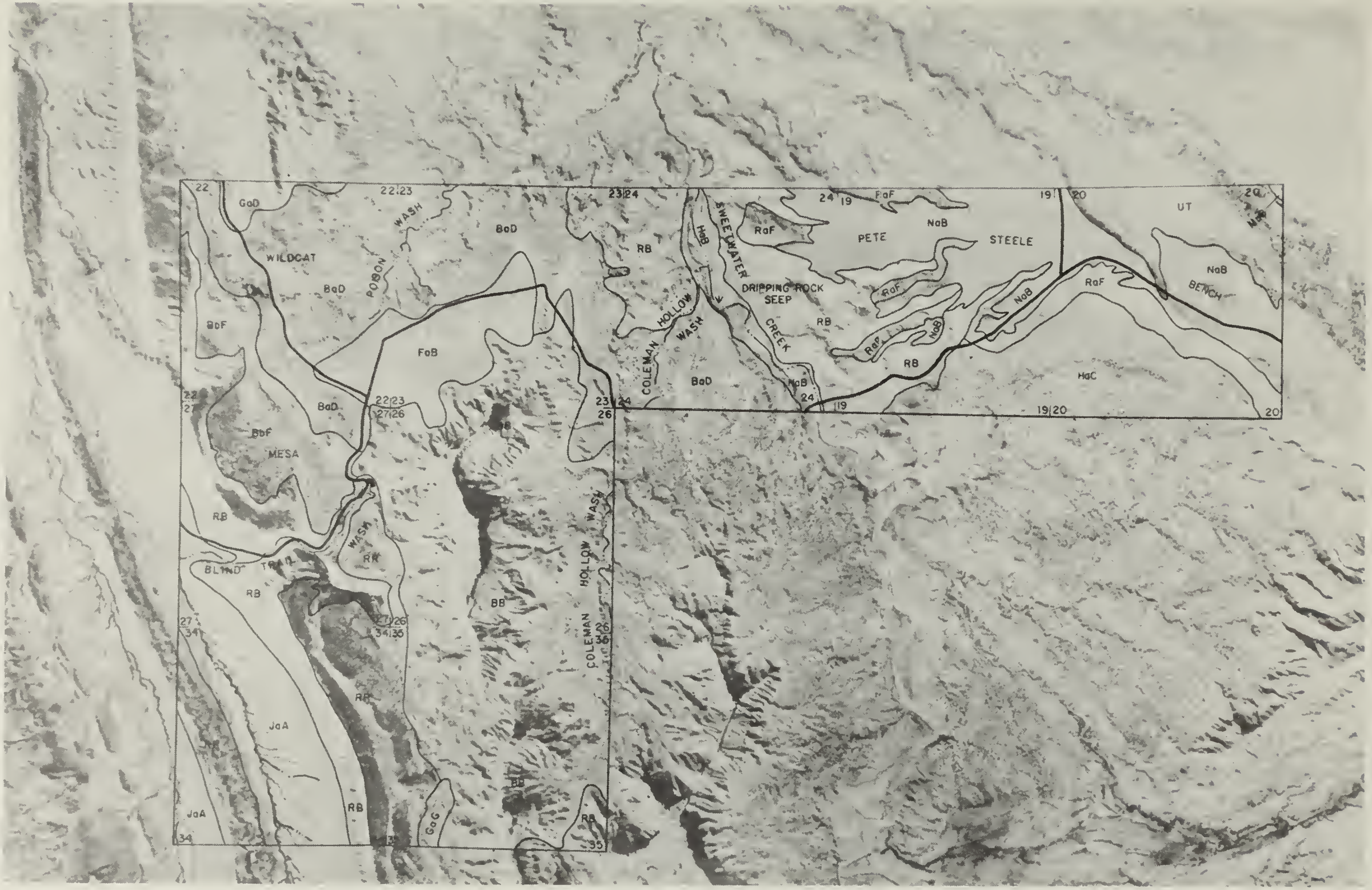


Figure 20b. Continuation of soil survey map of study area. Henry Mountains Resource area. (Sheet 2 of 2)

Table 15. Analytical data from major soils in the vicinity of Pete Steele Bench and Wildcat Mesa.

	DEPTH IN INCHES		PARTICLE SIZE DISTRIBUTION (in mm) (percent) (*)								% >2 mm.	TEXTURAL CLASS	pH		ORGANIC MATTER		GYPSUM %
			VERY COARSE SAND 2-1	COARSE SAND 1-0.5	MEDIUM SAND 0.5-0.25	FINE SAND 0.25-0.10	VERY FINE SAND 0.10-0.05	SILT 0.05-0.002	CLAY <.002	SAND <2 mm %			SATURATED PASTE	1:6	ORGANIC CARBON %	NITROGEN %	
Ba		A1															
	0-6	C	.3	1.1	3.8	48.7	12.6	15	18	67	0	FSL	7.6	8.4	.42	.04	<1
	6-12	R	1.1	1.6	3.1	49.4	13.9	19	12	69	0	FSL	7.7	8.3	.79	.05	<1
Fa	0-3	A1	0	.6	6.2	54.5	23.0	8	8	84	0	LFS	7.6	8.6	.33	.03	<1
	3-21	C1	.2	.7	7.2	48.0	20.0	12	12	76	0	FSL	7.5	8.6	.43	.04	<1
	21-40	C2	.2	.7	6.5	43.0	22.6	13	14	73	0	FSL	7.7	8.7	.62	.04	<1
	40-54	C3	.3	1.2	8.9	42.7	20.6	13	13	74	0	FSL	7.8	9.0	.28	.03	<1
	54-64	C4	1.1	2.5	12.4	45.3	15.1	13	11	76	12	FSL	8.0	9.3	.33	.03	<1
Ga	0-3	A1	.1	.1	.2	2.2	7.2	47	43	10	0	SiC	7.8	7.8	.33	.04	1.9
	3-12	C1	.1	0	.1	1.3	6.1	46	46	8	0	SiC	7.8	8.0	.45	.05	1.0
Ha	0-5	A1	0	.2	2.3	36.0	24.4	17	20	63	0	FSL	7.5	8.7	.40	.03	<1
	5-20	C1	0	.1	2.3	35.4	26.3	22	14	64	0	FSL	7.7	9.0	.26	.02	<1
	20-36	C2	0	.1	1.3	35.0	28.8	22	13	65	0	FSL	7.6	8.8	.14	.02	<1
	36-70	C3	0	.7	5.9	50.3	20.2	13	10	77	0	FSL	7.7	8.5	.13	.01	.3
Ja	0-9	A1	0	.1	.2	5.9	20.5	51	22	27	0	SiL	7.6	8.6	.42	.04	<1
	9-16	C1	.1	.4	.7	12.0	22.5	45	19	36	0	L	7.6	8.5	.31	.03	<1
	16-21	C2	.5	.6	.7	9.6	21.8	45	22	33		L	7.3	8.3	.45	.05	.2
	21-34	C3	.1	.1	.1	7.6	18.3	54	20	26	0	SiL	7.2	8.0	.41	.04	.4
	34-72	C4	0	.1	.2	7.9	18.1	53	21	26	0	SiL	7.8	8.3	.37	.04	2.4
Ma	0-2		2.0	2.8	3.1	19.9	37.7	26	9	65	17	vfSL	8.2	8.9	.56	.05	<1
	2-9		2.2	2.8	3.2	20.0	34.6	23	14	63	19	vfSL	8.1	8.9	.46	.05	<1
	9-18		1.0	2.4	3.2	19.2	28.0	23	20	54	5	SCL	8.2	9.0	.60	.07	<1
	18-26		1.9	2.7	3.6	14.1	13.0	32	15	35	16	CL	8.3	9.0	.71	.07	<1
	26-48		13.6	9.9	7.6	18.8	12.4	22	16	62	54	SL	8.4	9.4	.66	.06	<1
Na	0-7		4.0	3.8	7.3	30.7	27.7	17	10	73	12	fSL	8.3	9.0	.48	.05	<1
	7-16		1.7	3.4	7.5	29.5	22.3	18	18	64	7	fSL	8.2	9.0	.55	.06	<1
	16-39		.9	1.5	2.8	18.8	12.5	27	36	37	16	CL	8.6	9.4	.62	.04	<1
	39-48		2.5	2.8	3.9	20.4	17.3	28	25	47	39	SCL	8.5	9.2	.57	.05	.1
Pa	0-2		2.8	1.6	2.2	22.4	34.0	22	15	63	26	vfSL	8.2	9.1	.51	.05	<1
	2-10		1.2	1.2	2.2	21.2	30.5	24	20	56	14	vfSL	8.1	8.9	.60	.08	<1
	10-26		4.1	3.7	8.5	28.5	11.6	22	21	57	37	SCL	8.2	9.1	.41	.04	<1
	26-40		7.9	5.3	8.2	27.4	14.7	19	18	63	57	fSL	8.4	9.3	.47	.04	<1
Ra	0-8		5.6	4.0	3.0	17.6	26.5	30	13	57	35	vfSL	8.0	9.0	.60	.06	<1
	8-15		1.9	2.0	1.9	21.1	23.6	31	18	51	18	L	8.0	8.9	.63	.08	<1
	15-30		.3	.4	.9	36.1	18.2	25	19	56	2	fSL	8.2	9.1	.43	.05	<1
	30-48		.1	.3	.6	40.4	20.5	25	13	62	1	fSL	8.7	9.4	.22	.02	<1

Table 15. Analytical data from major soils in the vicinity of Pete Steele Bench and Wildcat Mesa. (Continued)

	ELECTRICAL CONDUCTIVITY MILLIMHOS PER CM @25°C	CaCO3 equivalent %	MOISTURE TENSIONS					CATION EXCHANGE CAPACITY	EXTRACTABLE CATIONS ← MILLIEQUIVALENTS PER 100G →				SODIUM			BASE SATURATION %	DRY BULK DENS. g/cc
			SATURATION %	1/10 ATMOS. %	1/3 ATMOS. %	15 ATMOS. %	AIR DRY %		Ca	Mg	Na	K	WATER SOLUBLE Na	EXCH. Na	EXCH. Na %		
Ba	.3	11.9	27.0	17.1	12.5	6.8	.7	5.5	*	1.0	.1	.2	<.1		2	--	1.9
	.4	13.2	33.0	20.3	13.5	5.0	.6	5.1		1.2	.1	.1	<.1		2	--	2.1
Fa	.4	2.7	28.0	11.9	5.3	2.8	.4	4.3	*	1.0	.1	.2	<.1		2	--	--
	.4	5.9	30.0	17.1	8.7	4.5	.8	6.6		2.2	.2	.2	<.1		3	--	--
	.4	6.5	27.0	21.2	10.4	4.8	.9	7.9		4.3	.2	.1	<.1		3	--	1.7
	.5	5.9	26.0	20.0	9.7	4.7	1.0	6.8		5.1	.3	.1	.1		4	--	--
	.6	7.8	30.0	18.5	8.6	4.2	.7	5.7		5.1	.6	.1	.2		8	--	--
Ga	5.7	.4	46.0	30.4	18.6	11.2	3.2	16.8	**	6.6	4.1	.5	1.9	2.2	14	--	1.4
	22.0	.2	66.0	34.6	25.9	14.6	3.2	17.9	**	10.9	20.1	.5	13.7	6.4	38	--	1.6
Ha	.8	9.5	37.0	21.4	11.4	5.9	1.6	9.0	*	4.2	.3	.3	.1		2	--	1.5
	.4	9.2	35.0	21.9	11.5	5.3	1.2	8.3		6.1	.2	.2	<.1		2	--	1.6
	1.9	7.9	35.0	23.3	10.7	4.9	1.3	7.9		5.5	.6	.1	.2		5	--	1.4
	6.6	5.7	30.0	13.1	8.1	3.8	.9	5.7		5.1	1.8	.1	1.3		9	--	--
Ja	.8	10.7	34.0	28.9	15.2	6.7	1.3	9.2	*	2.4	.2	.9	<.1		2	--	1.4
	.7	11.8	33.0	28.0	12.4	5.5	1.1	8.4		2.3	.2	.3	<.1		2	--	1.4
	2.0	13.4	37.0	27.6	14.3	7.1	1.4	9.5		2.8	.3	.2	.1		3	--	1.4
	3.2	12.3	37.0	28.5	15.0	6.4	1.5	9.5		3.9	.5	.2	.2		3	--	1.3
	17.8	11.4	37.0	17.6	16.6	7.2	2.0	8.9		8.9	5.1	.3	3.8		14	--	--
Ma	.5	1.5	27.6		7.0	4.1	1.2	7.1	*	1.8	.5	.8	<.1	.5	7	*	
	.4	3.1	28.4		8.5	5.5	1.2	9.3		2.1	.2	.9	<.1	.2	2		
	.3	10.5	36.6		14.8	8.6	1.6	12.3		3.8	.3	.4	<.1	.3	2		
	.4	54.4	47.3		22.0	12.6	1.2	8.1		4.4	.4	.2	.1	.3	3		
	2.9	3.1	35.7		13.2	7.1	1.0	6.3		6.2	1.4	.1	1.1	.3	5		
Na	.4	2.5	26.5		6.2	3.9	1.1	7.0	*	1.8	.3	.9	<.1	.3	4	*	
	.3	11.6	34.5		11.3	7.2	1.5	7.2		1.8	.3	.5	<.1	.3	4		
	.9	52.5	49.5		26.4	11.5	1.3	5.6		5.6	.8	.2	.3	.5	9		
	3.6	46.0	52.8		24.4	14.8	2.6	8.7		8.8	2.2	.2	1.9	.3	3		
Pa	.5	3.1	25.9		8.8	5.5	1.3	8.8	*	2.0	.4	.9	<.1	.4	5	*	
	.4	8.0	36.2		11.2	7.0	1.6	10.6		2.3	.2	.6	<.1	.2	2		
	.4	31.6	31.5		13.4	6.2	.9	6.2		3.7	.3	.2	<.1	.3	5		
	.4	23.2	32.5		11.1	5.5	.9	6.5		5.3	.3	.2	.1	.2	3		
Ra	.4	13.0	30.7		10.1	5.9	1.2	8.6	*	2.1	.3	.5	<.1	.3	3	*	
	.4	21.9	36.9		13.1	7.7	1.3	10.9		3.1	.3	.3	<.1	.3	3		
	.4	19.8	38.0		13.5	6.9	1.4	10.3		5.2	.2	.1	<.1	.2	2		
	.6	16.7	45.0		12.8	6.9	1.5	10.3		8.9	1.0	.2	<.1	1.0	10		

Table 16. A general assessment of the soils described in the Henry Mountains resource area soil survey for properties important to land rehabilitation.

	Texture	Slope (%)	Depth (in.)	Permeability	Erosion Hazard	Other Side Factors	AWC[1] (inches)
BaD[2]	fine sandy loam	4-15	6-20	moderate	severe	gravel pavement	1-2
FaB	loamy fine sand	2-4	42+	moderately rapid	moderate		7
BaD	silty clay	2-15	10-16	slow	severe	badland and rock outcrop	1-2
GaG	gravelly silty clay	30-60	10-16	slow	severe		1-2
HaB	fine sandy loam	2-4	60+	moderately rapid	moderate	badlands	7
HaC	fine sandy loam	4-8	60+	moderately rapid	moderate	badlands	7
JaA	silt loam	0-2	60+	moderate	moderate	badlands	7
MaB	very fine sandy loam	2-4	60+	moderately rapid	moderate	gravel and cobble pavement	5
NaB	fine sandy loam	2-4	60+	moderate	moderate	gravel substratum	6
PaD	gravelly very fine sandy loam	4-15	60+	moderately rapid	moderate	gravel substratum	5
RaF	cobbly very fine sandy loam	15-40	60+	moderate	severe		
RR	rock outcrop						
UT	sandy loams and gravelly sandy loams	0-2	60+	rapid	severe		

[1] For more detailed information see soil survey report on Henry Mountain resource area.

[2] Available water capacity.

[3] Ba soil mapped in complex with rock outcrop BaD, 40% Ba soil 35% rock outcrop BbF, 70% rock outcrop 25% stony sandy loam

Table 17. Suitability ratings of soils as plant growth media for disturbed land rehabilitation.

	Suitability Rating		
Factors Affecting Use	Good (G)	Fair (F)	Poor (P)
EC_e (mmho/cm)[1]	< 4	4-12	> 12
ESP Clay[2]	< 2	2-10	> 10
Sand	< 4	4-20	> 20
pH (Saturated paste)	6.5-8.5	5.0-6.5	< 5.0
		8.5-9.5	> 9.5
Boron (ppm, cold water soluble)	< 0.5	0.5-2.0	> 2.0
Rock and Gravel (% by Volume)	< 15%	15-30%	> 30%
Soil Texture	Loam, Sandy Loam, Loamy	Silt, Silt Loam	Silty Clay, Clay, Gravel or Rock
Bedrock Depth	> 40 in.	20-40 in.	< 20 inches
Slope	< 8%	8-15%	> 15%
K factor[3]	< .37	.37-.44	> .44

1. Electrical conductivity of saturation extract.
2. Exchangeable sodium percentage.
3. K factor is a coefficient of soil erodability.

texture (particle size distribution, including rock and gravel) were the principal factors in determining soil suitability in rehabilitation.

The soils most suitable for rehabilitation purposes in the vicinity of the study site are located in the soil mapping units designated as FaB, HaB and HaC (Table 18 and Figure 20). These soils are deep, with little or no rock and gravel. They presently support good stands of native grasses and shrubs and are some of the most productive soils in the immediate area. However, the soils are mainly fine sandy loams which are subject to wind erosion.

The NaB, MaB and JaA soils are moderately deep, but the NaB and MaB soils become increasingly gravelly and rocky with depth, and the JaA soil becomes saline at greater depths. The BaD, BbF, PaD and RaF are very shallow and/or very rocky. Small localized areas might provide suitable soil for vegetation establishment. The GaD and GaG soils are very saline, shallow, marineshale-derived soils with little potential for supporting vegetation other than mat saltbush.

2. Greenhouse Fertility Study of Surface Soils and Rock Outcroppings

Samples of surface soils or outcrop materials from 6 field sites were collected and tested for toxicities and fertility in the greenhouse. The same general procedures were used in this study as in the core bioassay, except that N and P were each varied from 0 to 90 ppm in a factorial arrangement. There were three replications of each treatment.

A positive growth response of Russian wildrye to added nitrogen was observed in both soils and outcrop materials (Figure 21). The combination of nitrogen and phosphorus had a greater effect on plant growth than the type of soil surface material. The significant interactions of soil type with N or P indicate the varying fertility status among the soil materials

Table 18. Suitability of soils for rehabilitation (See Table 13 for explanation of suitability ratings).

Factors	Soil Designations (See Soils Map)									
Affecting Use	BaD	BbF	FaB	GaD GaG 1/	HaB HaC 1/	JaA	MaB	NaB	PaD	RaF
EC_e	G	G	G	P	G-F	G-P	G	G	G	G
ESP	G	G	G-F	P	G-F	G-F	G-F	G-F	G-F	G-F
pH	G	G	G	G	G	G	G	G	G	G
Rock and Gravel	G	F	G	G	G	G	F-P	F-P	F-P	F-P
Soil Texture	G	P	G	P	G	G-F	G-P	G-P	G-P	G
Bedrock Depth	P	P	G	P	G	G	G	G	F	G
Slope	F	P	G	G-P	G	G	G	G	G-F	P
K Factor	G	G	G	G	G	F	G-F	G	G	G
Over-all Rating	P	F	G	P	G	F	F	F	P	P
			*		*					

* = (Best soils to use)

1/ These two soils are very similar in the soil survey and were shown together here only for purposes of interpretation.

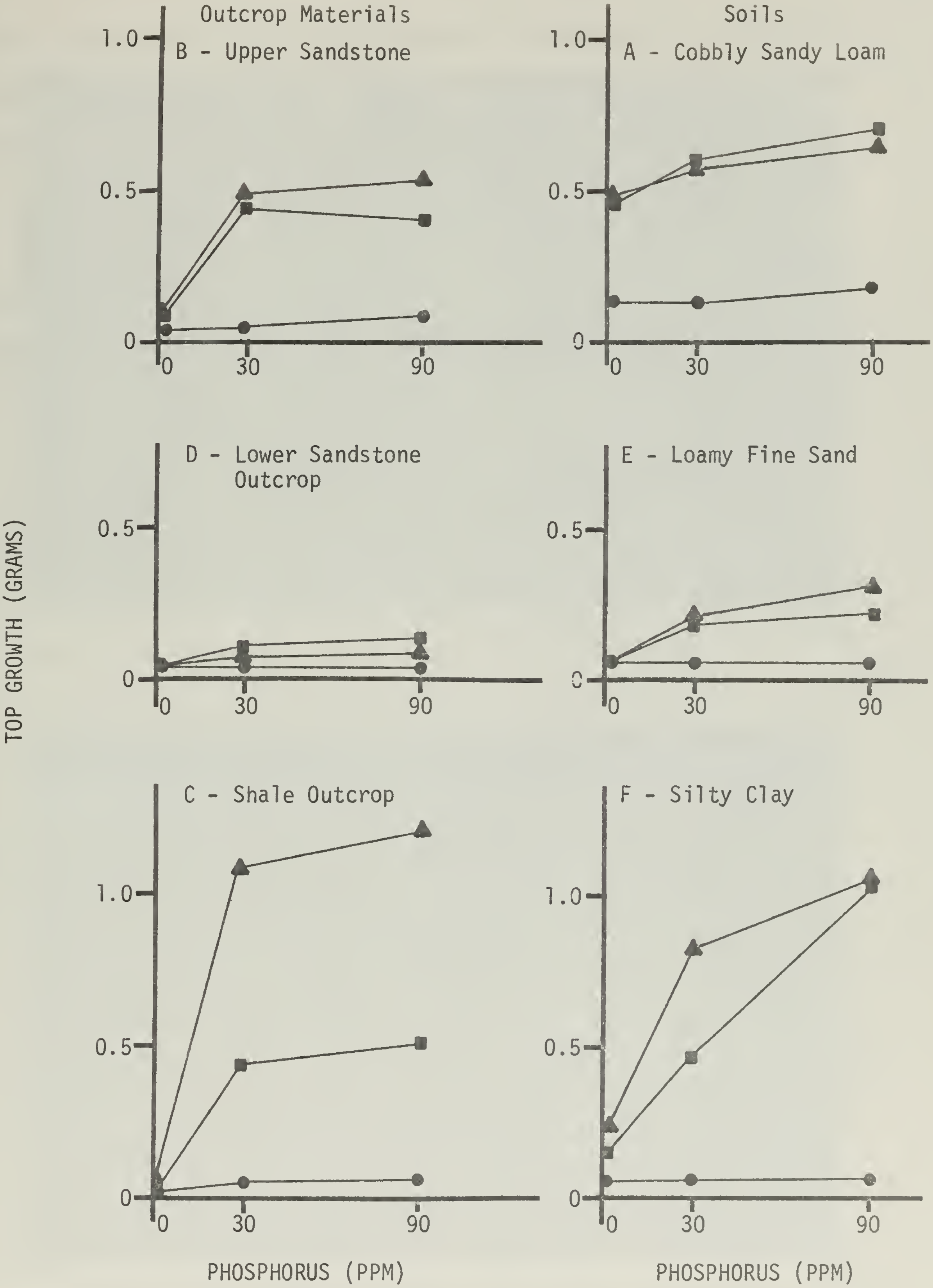


Figure 21. Top growth of Russian wildrye in the greenhouse in response to added nitrogen and phosphorus on growth media from 6 field sites (● = 0 ppm N, ■ = 30 ppm N, ▲ = 90 N). Means of 3 replications.

(especially clay vs sand). The significant N and P interaction indicates that both N and P are required for a fertilizer response. The limited plant growth response to N and P on the lower sandstone outcrop suggests that other factors are limiting.

The general conclusion from the study of geologic outcrop materials is that fertilization of spoil materials will enhance plant growth considerably if adequate soil moisture is available. The actual amounts of fertilizer required under arid field conditions remain to be determined.

The chemical analyses (refer to Table 10) indicate that the soils (sites A, E, F,) are more fertile than the outcrop materials (sites B, C, D); that is, they contain more N, P and K. Therefore if these soils were used in revegetation they would require considerably less fertilizer than the geologic materials.

3. Plant Establishment in the Field and Survival on Soil and Outcrop Materials

Six field sites (A through F) on representative soils and outcrop surface materials were selected. Three sites were on soils (A, E, F), and three were on partially weathered outcroppings of geologic materials (B, C, D). Sites B, C, and D were repeatedly scraped and then leveled with a bulldozer. Existing vegetation was removed by hand from sites A, and F. A bulldozer was used to remove the rhizomatous galleta grass from site E.

The soil at site A, on Pete Steele Bench, (Figure 22) lies within the NaB soil mapping unit of the Henry Mountains soil survey. The soil is a highly calcareous, cobbly sandy loam. Vegetation at site A is mainly galleta grass, blue grama grass, fourwing saltbush, and broom snakeweed.

Figure 22. Revegetation study site A, Pete Steele Bench.

Figure 23. Site E, Wildcat Mesa.

The site E soil on Wildcat Mesa (Figure 23) is a deep aeolian deposit of loamy fine sand. It falls within the FaB soil mapping unit. Vegetation at the site is dominated by galleta grass with scattered fourwing saltbush and shadscale.

The soil at site F on Wildcat Mesa (Figure 24) corresponds to the GaD silty clay mapping unit. This very shallow, saline soil is derived from marine shale, (Masuk) deposits. The soil has a high content of expanding clay as indicated by the great degreee of soil cracking upon drying. Native vegetation is almost solely mat saltbush.

Site B consists of a very shallow rocky outcrop of crushed and broken sandstone fragments 9 to 12 inches deep overlying a sandstone bedrock (Figure 25). This site is three-fourths of the way up the road to Pete Steele Bench and corresponds to unit 2 of the surface section description of the escarpment in Table 7.

Site C is on an outcrop of the Pete Steele Bench escarpment (Figure 26) and consists of 12 to 18 inches of crushed gray shale overlying shale bedrock. The site is saline (EC_e 9.5 mmho/cm) and acidic (pH 4.7). Some coal fragments are present. Natural vegetation on the shale is cuneate saltbush. This site was located on unit 4 of the Pete Steele Bench escarpment (Table 7).

At site D, at the base of the Pete Steele Bench escarpment (Figure 27) 12 to 18 inches of finely crushed sandstone overlie sandstone bedrock. The soil material is saline (EC_e 9.5 mmho/cm) and lies just above a coal bed. This site corresponds to unit 5 of the Pete Steele Bench escarpment section description (Table 7).

A supposedly rodent-proof fence was installed prior to planting at each of the six sites. This consisted of 2.5 cm (1 in.) netting, 1.2 m

Figure 24. Site F, Wildcat Mesa.

Figure 25. Revegetation study site B, Pete Steele Bench escarpment.

Figure 26. Site C, Pete Steele Bench escarpment.

Figure 27. Site D, Pete Steele Bench escarpment.

(4 ft.) high and with barbed wire around the top. The bottom of the fence was buried with a 10-15 cm (4-6 in.) section turned out to prevent animals from burrowing under it. The fence surrounding site C was stolen and removed sometime between May 6 and 20, 1977; this was replaced June 18, 1977.

Container grown stock (5X5X30 cm paper containers) was produced at Utah State University, Logan, and at the Snow Field Station, Ephraim. Plants of cuneate saltbush and shadscale were vegetatively propagated from cuttings. Fourwing saltbush was propagated from seed. Plants of Russian wildrye were grown from commercial seed, and Indian ricegrass was propagated by clone separation from indigenous plants.

Three plants of each species were planted for each of two treatments: one a control and one with a 20-20-20-(NPK) soluble material applied at the rate of 112 kg/ha (100 lb/A) in one liter (1.1 qt.) of water per plant following planting. It was assumed that these soluble nutrients would be more available for root uptake in this arid climate. Both the control and fertilized plants received 2 liters of water following the planting. Water containing the nutrient solution was included in the 2 liters. There were 4 replications (3 plants per species) at each site, making a total of 24 plants per species per site for a total of 144 plants per species for the 6 sites. All plants were on a 1 m x 70 cm spacing, except at site D which was on a 70 x 70 cm spacing. Field plantings were made on April 14 and 15, 1977.

It was realized early that all plants would probably die due to drought conditions if supplementary water was not applied at regular intervals, or until beneficial amounts of precipitation fell. Because the major objective was to compare differences in survival and growth of plants due to soil type and fertilizer, addition of water was justified. Two liters of water per plant were applied at approximately 2 week intervals throughout the growing season, until September 14, 1977. A total of 22 liters, including the initial watering at time of planting, were applied to each plant. Fertilizer was added only at planting.

Table 19 shows the percent survival of the five transplanted species as of September 14, 1977. There were no differences between the fertilized and unfertilized treatments during this drought year and therefore the two treatments were averaged. Despite the one inch mesh fences at each site, some rodent damage occurred. This may account for the extremely poor survival of fourwing saltbush at sites A and E, and of Russian wildrye plants at site A. Fourwing saltbush is an important component of the native vegetation of site A and also occurs at site E. The fence, stolen from site C sometime between May 14 and June 18, resulted in some damage by cattle and rodents before it was replaced.

When averaged across species, greatest plant survival occured at site D, (Figure 28) followed by sites E and B. All three are sandy, or sandy and stony in texture. Survival on site B is surprisingly high considering its shallow, rocky nature (Figure 29). Perhaps, perching of applied irrigation water on the sandstone bedrock contributed to plant survival. Perched water also may have been responsible for high survival on site D. Poorest survival occurred on the clay or shaley sites C and F. In contrast to the best field survival occurring on sandy textured soils or outcrop materials, the best growth in the greenhouse was on the fine textured materials (Table 20). These apparently conflicting results must be evaluated in terms of many factors especially the arid conditions of the field study site.

Table 19. Percent survival of transplants on six field sites after five months (Planted April 14, 1977).

Site	Fourwing Saltbush	Shadscale Saltbush	Cuneate Saltbush	Indian Ricegrass	Russian Wildrye	Site Averages
A. Cobbly sandy Loam, Pete Steele Bench	0	33	88	38	4	32.6
B. Crushed sandstone outcrop	67	63	69	29	67	59.0
C. Crushed gray shale outcrop	13	67	26	21	21	29.6
D. Crushed saline sandstone outcrop	84	100	100	88	100	94.4
E. Loamy fine sandy soil, Wildcat Mesa	0	25	44	92	100	52.2
F. Silty clay soil, Wildcat Mesa	13	34	7	0	8	12.4
Species Averages	29.5	53.7	55.7	44.7	47.8	

Figure 28. Close-up view of study site D.

Figure 29. Close-up view of study site B.

Table 20. A comparison of growth in greenhouse and field survival of Russian wildrye on surface outcrop materials and soils of the Henry Mountains Coal Field study area.

Soils and Outcrop Materials

Study Plot	Growth in Greenhouse (mg)	Field Survival (%)
A. Cobbly sandy loam, Pete Steele Bench	590	4
B. Crushed Sandstone (outcrop)	517	67
C. Crushed Shale (outcrop)	1112	21
D. Crushed Sandstone (outcrop)	82	100
E. Loamy Fine Sand, Wildcat Mesa	208	100
F. Silty Clay, Wildcat Mesa	825	8

G. Vegetation

A generalized map of the potential natural vegetation of the United States (Küchler, 1964) shows three vegetation types for the Henry Mountains area: Arizona pine forest on the upper slopes of the mountains, juniper pinyon woodland on the plateaus and low valleys to the west of the mountains, and salt desert shrub in the low desert areas to the north of the Henry Mountains. The small scale of the Küchler map, however, precludes describing the degree of variability that exists in the study site. There is a widespread distribution of juniper and salt desert shrub-dominated plant communities throughout the general area west of the Henry Mountains.

Everett (1970) has apparently made the only detailed study of vegetation in the vicinity of the study area. He ran transects northeast of Mt. Ellen, from 9,000 feet off the north side of Bull Mountain toward Hanksville and the Dirty Devil River ending at about 4,000 feet. He identified 12 vegetation types and related them to environmental factors.

Everett also found considerable edaphic compensation. For instance, pinyon-juniper woodland was found to occur at elevations as low as 5,000 feet on indurated sandstone (Navajo and Salt members of the Morrison Formation) although it was not found below 6,000 feet on other substrates. Other types were also related to resisance of the rock and its impact on soil formation and movement and soil water holding capacity. Many of his observations should hold for the area being considered in this report since the same geological formations, the same climatic patterns and similar grazing use history are involved.

For the general area of the study site the potential vegetation cover is a sparse stand of juniper with a shift in understory plant communities to scattered shrub-juniper communities on shallow and rocky soils of badland areas and grass-shrub communities on the tablelands where soils are more productive. Many of the same plant species are found on the twenty soil mapping units, and the five generalized range soil types (USDA Soil Conservation Service, 1977).

The steeply sloping areas and badlands have shallow soils or rocky outcrops resulting in a sparse vegetal cover. High erosion rates tend to keep the productivity of such areas low (USDI Bureau of Land Management, 1975).

Limited and infrequent rainfall assures that only the most drought resistant or drought avoiding plant species grown in the general area. In dry years such as 1976-77, essentially no annual plant species occur.

Seven plant communities have been identified by Bureau of Land Management range surveys on the Henry Mountain Coal Field study site and adjacent areas (Figure 30). The principal communities are grass, sagebrush, pinyon-juniper, saltbush, greasewood, desert shrub and half shrub. These plant communities were studied on 69 transects located on representative sites throughout the study area (Table 21). Interpretations of the vegetative cover, species composition, and soil conditions in terms of rangeland use and carrying capacity will be discussed in the section on land use.

Each of the plant communities has a general tolerance for soil conditions and topographic features. These tolerances in turn influence species composition of the community. Criteria for land rehabilitation practices can be drawn from a knowledge of plant community composition, density and cover. Although many of the same species are found in each community, the proportions may change. According to soil and range surveys, the following vegetation types or plant communities may be observed:

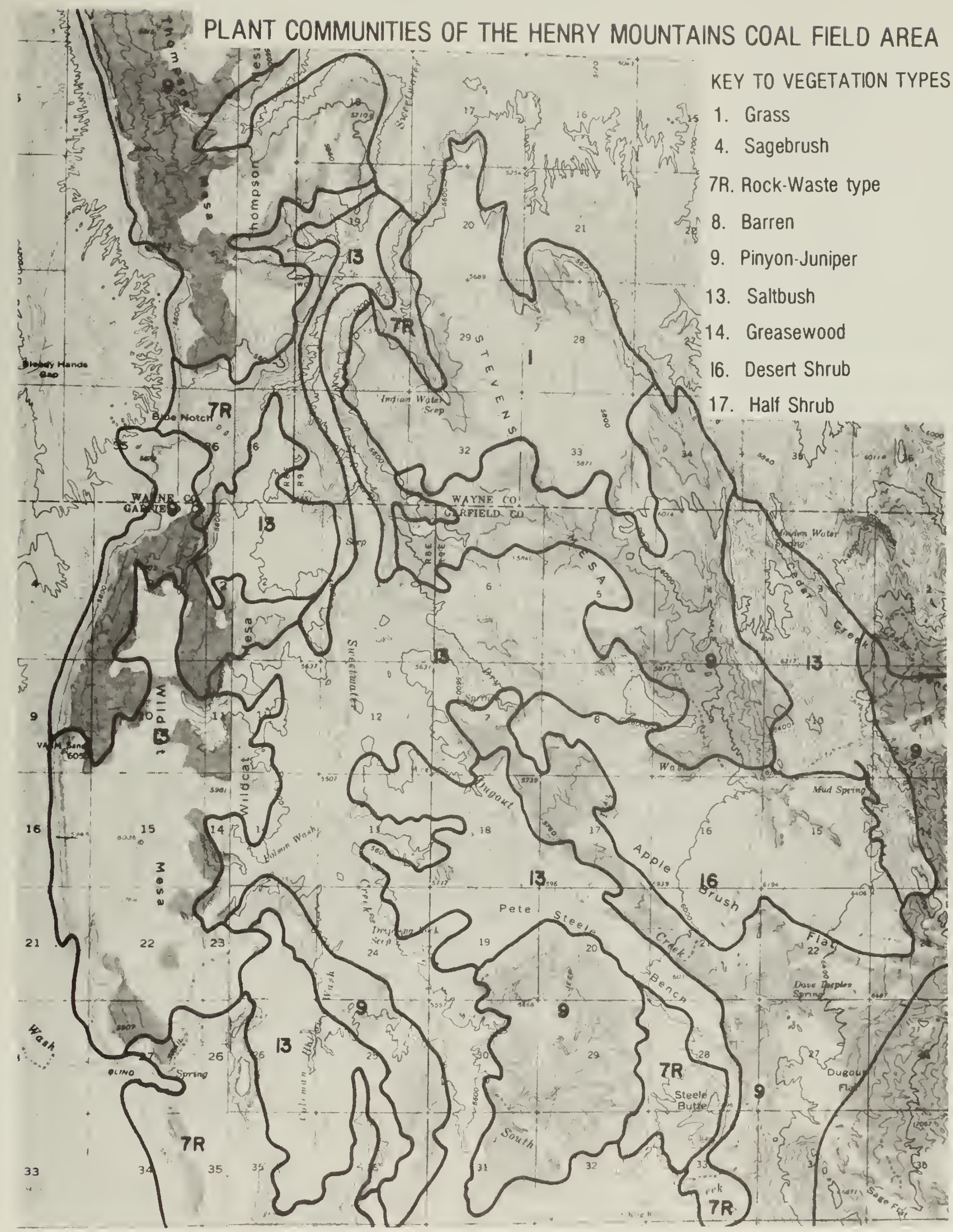


Figure 30. Plant communities of the Henry Mountains Coal Field. (Prepared from data in Bureau of Land Management Allotment Management Plan)

Table 21. Ground cover estimates for vegetation types adjacent to reclamation study sites within the Coal Lease Block Steele Butte Allotment Henry Mountain Resource Area, 1977. Data are from Bureau of Land Management, Allotment Management Plan.

<table>
<tr><th rowspan="3">Map Index No.</th><th rowspan="3">Transect[1] Number Designation</th><th rowspan="3">Vegetative Type (on Fig 24) and Species[2]</th><th colspan="5">Ground Cover (%)</th></tr>
<tr><th colspan="2"></th><th colspan="2">Rock</th><th></th></tr>
<tr><th>Veg.</th><th>Litter</th><th>SR</th><th>LR</th><th>Bare</th></tr>
<tr><td rowspan="2">1.</td><td rowspan="2">KR11,13</td><td rowspan="2">1(9)HIJA ATCO, JUOS</td><td>26</td><td>22</td><td rowspan="2">3</td><td rowspan="2">0</td><td rowspan="2">49</td></tr>
<tr><td colspan="2">48</td></tr>
<tr><td rowspan="2">2.</td><td rowspan="2">KR13,14,23</td><td rowspan="2">9 JUOS, GUSA</td><td>22</td><td>18</td><td rowspan="2">18</td><td rowspan="2">4</td><td rowspan="2">38</td></tr>
<tr><td colspan="2">40</td></tr>
<tr><td rowspan="2">3.</td><td rowspan="2">KR3,9</td><td rowspan="2">9 JUOS, HIJA, ATCO</td><td>17</td><td>20</td><td rowspan="2">6</td><td rowspan="2">1</td><td rowspan="2">56</td></tr>
<tr><td colspan="2">37</td></tr>
<tr><td rowspan="2">4.</td><td rowspan="2">B1,2</td><td rowspan="2">9 EPNE, GUSA</td><td>16</td><td>18</td><td rowspan="2">11</td><td rowspan="2">4</td><td rowspan="2">51</td></tr>
<tr><td colspan="2">34</td></tr>
<tr><td rowspan="2">5.</td><td rowspan="2">ZL1,8,9</td><td rowspan="2">9 JUOS, PIED</td><td>15</td><td>14</td><td rowspan="2">14</td><td rowspan="2">24</td><td rowspan="2">33</td></tr>
<tr><td colspan="2">29</td></tr>
<tr><td rowspan="2">6.</td><td rowspan="2">KR17,20 BL4,5
B14,5 BK5,ZL
28,29 30</td><td rowspan="2">9 JUOS, PIED</td><td>19</td><td>18</td><td rowspan="2">17</td><td rowspan="2">9</td><td rowspan="2">37</td></tr>
<tr><td colspan="2">37</td></tr>
<tr><td rowspan="2">7.</td><td rowspan="2">BL3 ZL27</td><td rowspan="2">9 JUOS, PIED</td><td>12</td><td>17</td><td rowspan="2">9</td><td rowspan="2">4</td><td rowspan="2">55</td></tr>
<tr><td colspan="2">29</td></tr>
<tr><td rowspan="2">11.</td><td rowspan="2">ZL18,19</td><td rowspan="2">13 ATCO</td><td>21</td><td>5</td><td rowspan="2">1</td><td rowspan="2">1</td><td rowspan="2">72</td></tr>
<tr><td colspan="2">26</td></tr>
<tr><td rowspan="2">12.</td><td rowspan="2">BL1,2,SB1
KR8,18 ZL16, 17
20,24,26</td><td rowspan="2">13 ATCO,SAVE,HIJA</td><td>18</td><td>16</td><td rowspan="2">2</td><td rowspan="2">1</td><td rowspan="2">63</td></tr>
<tr><td colspan="2">34</td></tr>
<tr><td rowspan="2">14.</td><td rowspan="2">SB2 KR2
B3,4</td><td rowspan="2">13 (1) ATCO,HIJA</td><td>20</td><td>24</td><td rowspan="2">4</td><td rowspan="2">3</td><td rowspan="2">47</td></tr>
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<tr><td rowspan="2">16.</td><td rowspan="2">BL6
KR21,22</td><td rowspan="2">13 (1) ATCO, HIJA,
ARNO</td><td>21</td><td>22</td><td rowspan="2">8</td><td rowspan="2">-</td><td rowspan="2">47</td></tr>
<tr><td colspan="2">43</td></tr>
<tr><td rowspan="2">20.</td><td rowspan="2">BK 7 BK15,19</td><td rowspan="2">16 (1) GRSP, BOGR,
JUOS</td><td>31</td><td>17</td><td rowspan="2">8</td><td rowspan="2">12</td><td rowspan="2">32</td></tr>
<tr><td colspan="2">48</td></tr>
<tr><td rowspan="2">22.</td><td rowspan="2">KR 4,7</td><td rowspan="2">1 ADGE</td><td>23</td><td>36</td><td rowspan="2">1</td><td rowspan="2">3</td><td rowspan="2">37</td></tr>
<tr><td colspan="2">59</td></tr>
</table>

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1. A transect is a sampling line used to collect vegetation data.

2. Symbols for plant names are composed of the first two letters of the generic name and of the species name. See appendix for scientific and common names of plants.

Grass (map unit 1).

This community is found on the plateaus and relatively level areas where soils are clay loam and sandy loam. Rooting depth is 20 to 35 inches. Permeability of the soils is generally slow. In some blow sand areas, rapid percolation allows the limited precipitation to escape evaporation loss and remain available, although deep, for plant growth. The major species are Indian ricegrass, galleta grass, grama grass, needle and thread, shadscale, fourwing saltbush, juniper, broom snakeweed, and desert mallow. An average plant cover percentage of 26 is probably higher than other types.

Sagebrush (map unit No. 4).

Sagebrush as a dominant vegetation type does not occur in the study area, but individual plants are found in the other types. On higher plateaus to the south, sagebrush may be seen as a dominant species. Plants of black sagebrush and bud sagebrush occur on shallow shale soils; low sagebrush occurs on semi-desert alkali fans and semi-desert gravelly loam, and big sagebrush is found on semi-desert loam sites. Because of the wide range of adaptation present in the species of sagebrush, they may occur on both shallow or deep soils, rocky or clay soils, and neutral to alkaline soils. Rooting depth is equally variable, but generally sagebrush roots penetrate in depth into the soil as well as laterally.

Rocky Wastelands (map unit 7R)

This is not a vegetation type although it is shown as such on the map units delineated by the Bureau of Land Management staff. These areas are the escarpments, talus slopes, rocky ravines, canyons and rock outcrops.

Pinyon-Juniper (Map unit No. 9)

The density of the pinyon pine and Utah juniper is limited and scattered. Because the vegetation type varies considerably over the entire study site and adjacent areas probably because the climate is marginal for pinyon and juniper. The stands of greatest density are on more favorable soil types and topographic locations. The two soil types where pinyon-juniper occurs in greatest abundance are the semi-desert shale slopes and alkali fans. Pockets of soil in the badlands areas also appear to be suitable pinyon juniper sites. Associated plant species include shadscale, rabbit brush, low sagebrush, snakeweed, galleta grass, Indian ricegrass, blue grama grass, alkali sacaton, and desert globe mallow. Vegetal cover averages 20 percent, but may be lower in years of drought.

Saltbush (map unit No. 13)

Various species of saltbush are found in all of the vegetation types on the study sites as well as on adjacent areas. The main soil types which support the saltbush dominated types are the desert shallow shale and the semi desert shale. Mat saltbush appears to be the best adapted species for saline-alkaline soils. Some associated species include black sagebrush, bud sagebrush, galleta, Indian ricegrass, green ephedra, and bull grass.

In previous BLM range surveys, estimated vegetative cover was 20 percent. Rooting depth of the shrubs is deep in contrast to the relatively shallow root depth of the grasses. Because of the 1976-77 drought, most grasses remained relatively dormant during the entire growing season, indicating a high drought tolerance for such species as galleta and Indian ricegrass. No annual forbs or grasses grew during the drought period.

Greasewood (Map unit no. 14)

This vegetation type is very limited in the coal field area. Individual plants may be found in the other vegetation types, but greasewood generally occurs along the banks of intermittent streams and gullies where deep soil moisture and heavy soils are found. Fourwing saltbush and annual forbs such as Russian thistle and halogeton are typical associated species.

Desert Shrub (Map unit No. 16)

The prime species in the desert shrub vegetation type is spiney hopsage. Associated species are juniper, blue grama, Indian ricegrass and broom snakeweed. Vegetative cover averages 21 percent. This type is found on the semi-desert, gravelly loam range site in the vicinity of Apple Brush Bench.

Half Shrub (Map unit No. 17)

This vegetation type is located south of Cove Flat Reservoir; the main species is broom snakeweed, a small short-lived suffrutescent shrub that reaches a maximum of 20-30 cm high. It generally invades open plant communities where overgrazing has reduced the competitive ability of existing species. Associated species are the same grasses of other types plus a few scattered fourwing saltbush plants. Vegetal cover is usually less than 20 percent. Soils are the semi-desert loam and gravelly loam range sites.

H. Sedimentation

1. Compilation of sediment discharge records available from existing stations in the region.

Utah State University (1975) recently completed a regional assessment study of the Colorado River for the National Commission on Water Quality. Summaries of STORET data were obtained from the U. S. Environmental Protection Agency for all water quality parameters at every recorded station in the Colorado River Basin. A map of the various STORET stations for the Upper Colorado River Basin is shown in Figure 31. Water quality parameters which may be evaluted from STORET data are shown in Table 22. Unfortunately, as may be seen in Figure 31, there are no stations listed which are in the immediate study area.

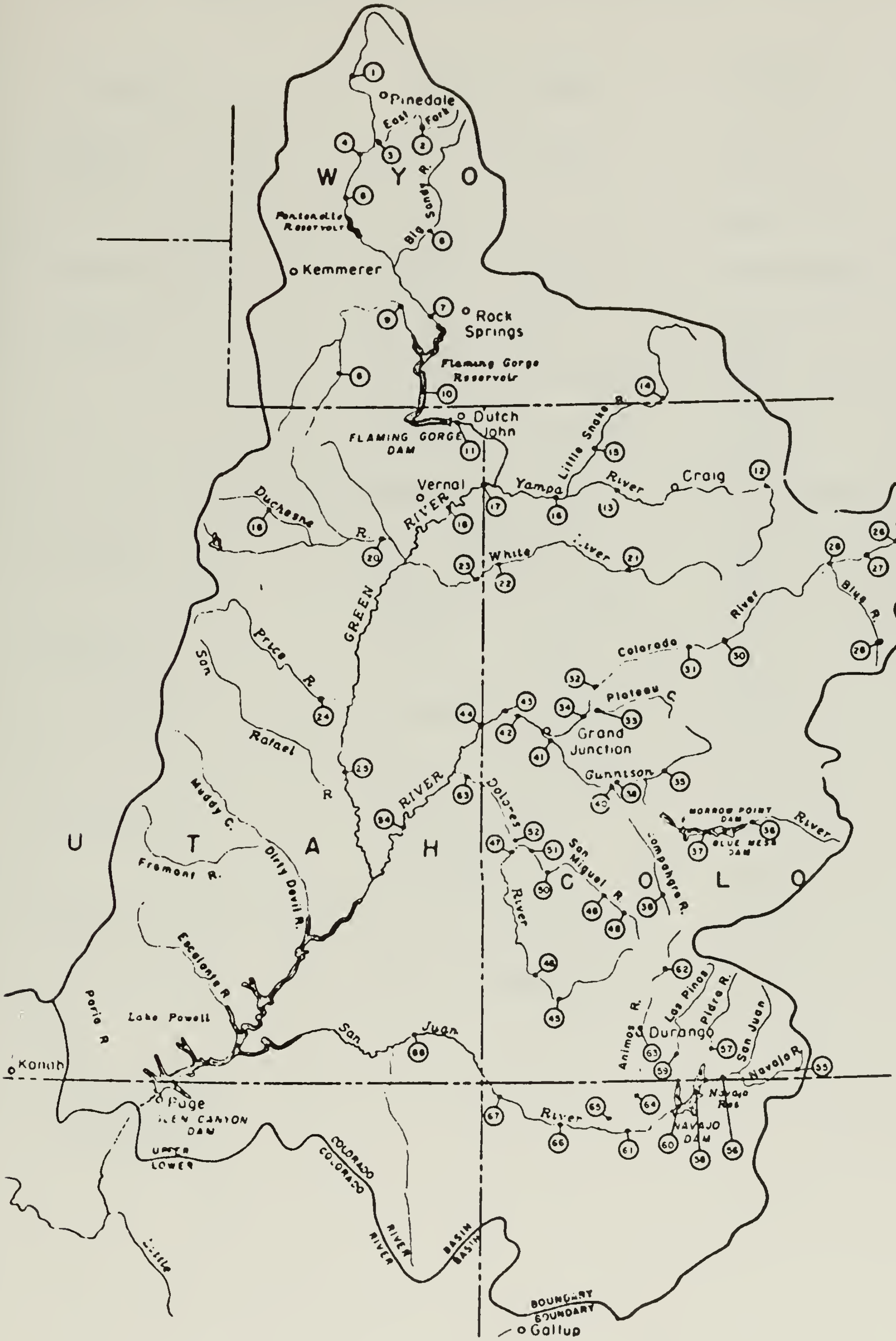


Figure 31. Water quality STORET stations for Upper Colorado River Basins. (Mundorf 1968 as cited by Utah Division of Water Resources - 1975)

Table 22. Water quality parameters in the Colorado River Basin evaluated from storet data.

Parameter	Storet Symbol		Units	Storet Code
Biochemical Oxygen Demand	BOD	5 DAY	mg/l	00310
Dissolved Oxygen	DO		mg/l	00300
Temperature	WATER	TEMP	Centigrade	00010
Salinity	DISS SOL	SUM	mg/l	70301
	RESIDUE	DISS-180C	mg/l	70300
	RESIDUE	DISS-105C	mg/l	00515
	CNDUCTVY	AT 25C	micromho	00095
Sediment	SUSP SED	CONC	mg/l	80154
	RESIDUE	TOT NFLT	mg/l	00530
Nitrogen	NH3-N	TOTAL	mg/l	00610
	NO2+NO3	N-TOTAL	mg/l	00630
	NO3	N-TOTAL	mg/l	00620
Phosphorus	SOLPO4-T	PO4	mg/l	00653
	ORTHORPHOS		mg/l	00660
Fecal Coliformes	FEC COLI	MPNECMED	100ML	31615
	FEC COLI	MFM-FCBR	100ML	31616
Other				
heavy metals pesticides radiation				

Apparently some very limited sediment discharge data have been compiled by Mundorff (1968, cited by Utah Division of Water Resources, 1975) for the Fremont River. As shown in Figure 32, sediment data for either the Fremont or Dirty Devil rivers would be meager. Figures 33 and 34 show sediment concentration and discharge respectively, on the Dirty Devil River at Hanksville for the years 1946-48.

Goode and Olson (1977) cited some U. S. Geological Survey sedimentation records from near Caineville for the period March, 1967 to May, 1972, as follows:

Water Year	Discharge (acre-feet)	Suspended load (tons)
1968	49,200	101,105
1969	46,750	414,519
1970	48,200	60,461
1971	54,400	171,441
October 1, 1971 to May 31, 1972	36,750	24,661

2. Sediment source area map for upland drainage basins in the report area.

The only known sediment yield map available is the generalized map given in the Upper Colorado Region Comprehensive Framework Study (1971). Sediment yields for the report area, as shown on the map, range from 0.2 to 1.0 acre feet mi^2 year.

3. Evaluation of stream channels to establish estimates of sediment conveyance to downstream reaches.

Such evaluations are currently not available.

4. Estimates of sediment delivery ratios from 2 and 3 above.

Estimates of sediment delivery ratios are currently not available. However, five different delivery-ratio relationships are shown in Figure 35, all of which were represented in the Proceedings of the 1972 Sediment

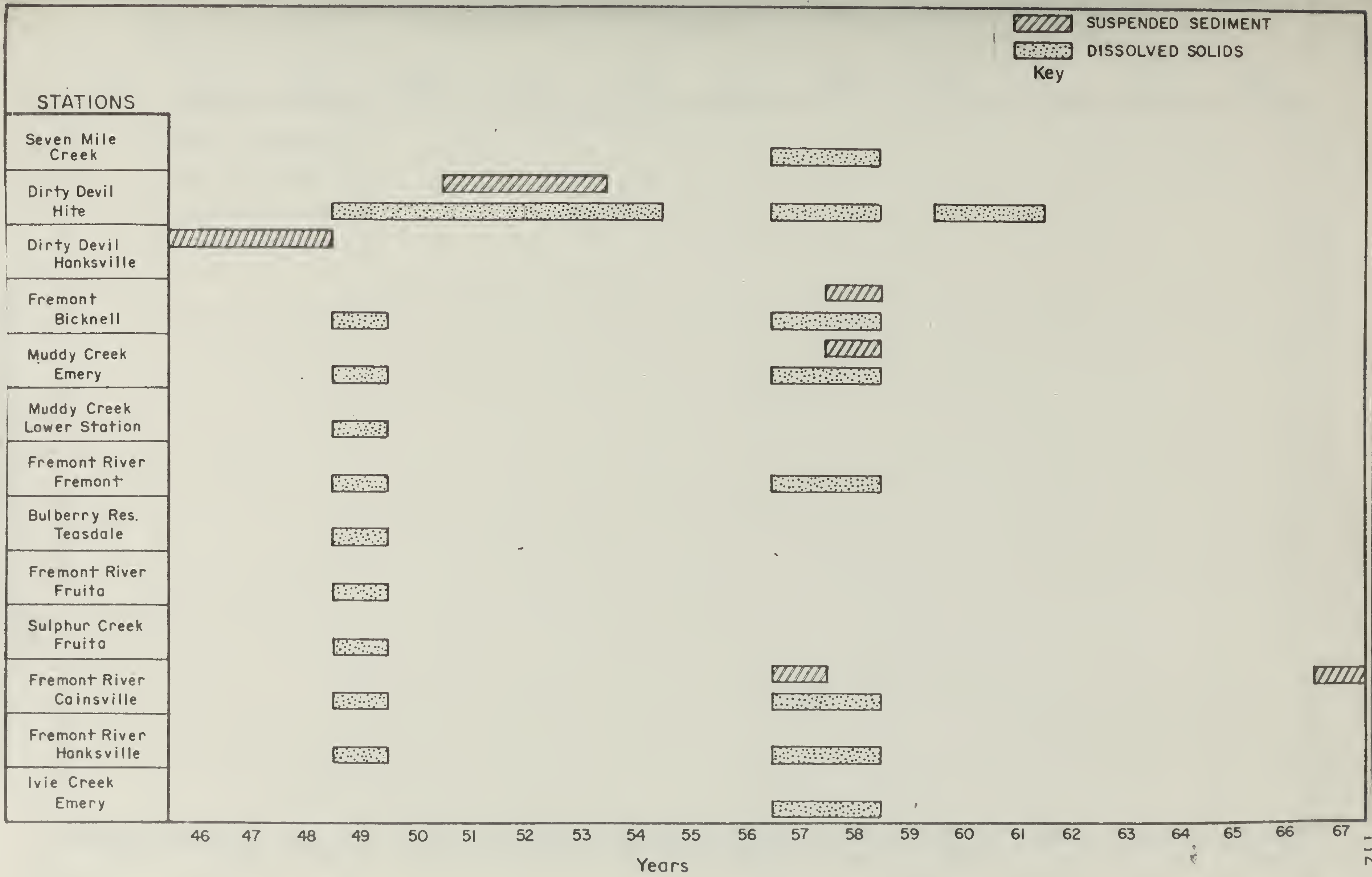


Figure 32. Water Quality Records Available.

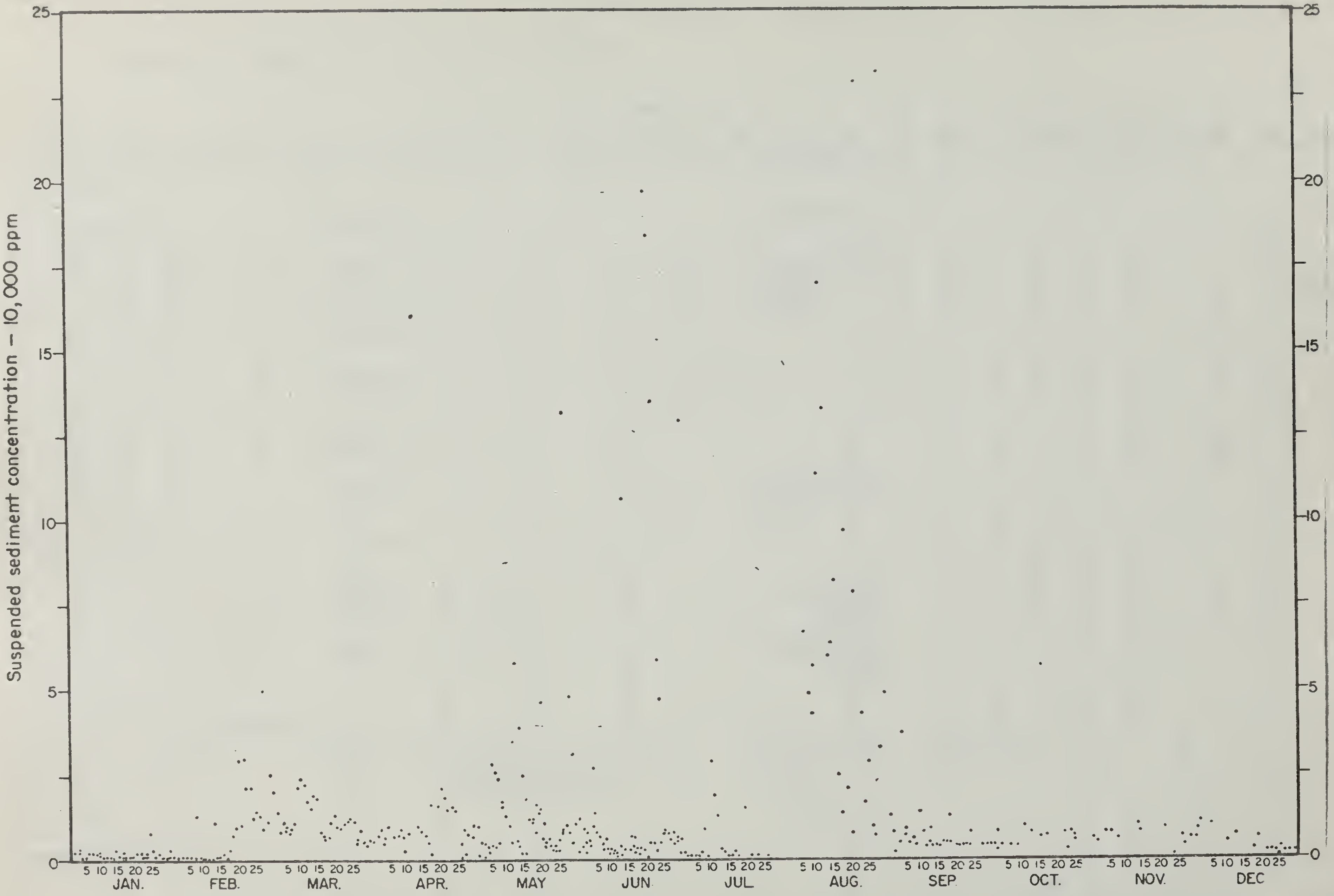


Figure 33. Dirty Devil River near Hanksville suspended sediment concentration - 1946-48.

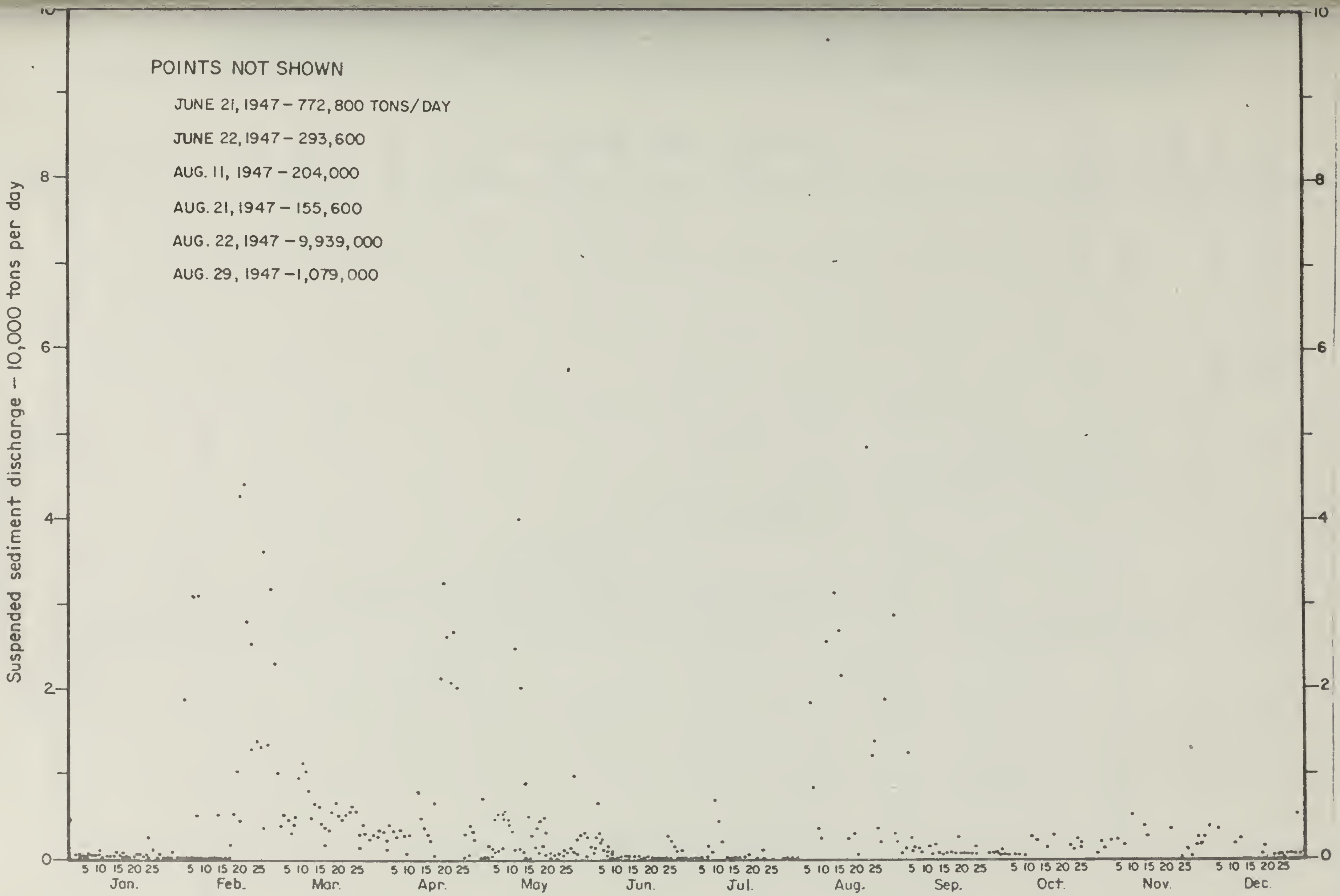


Figure 34. Dirty Devil River near Hanksville suspended sediment discharge - 1946-48.

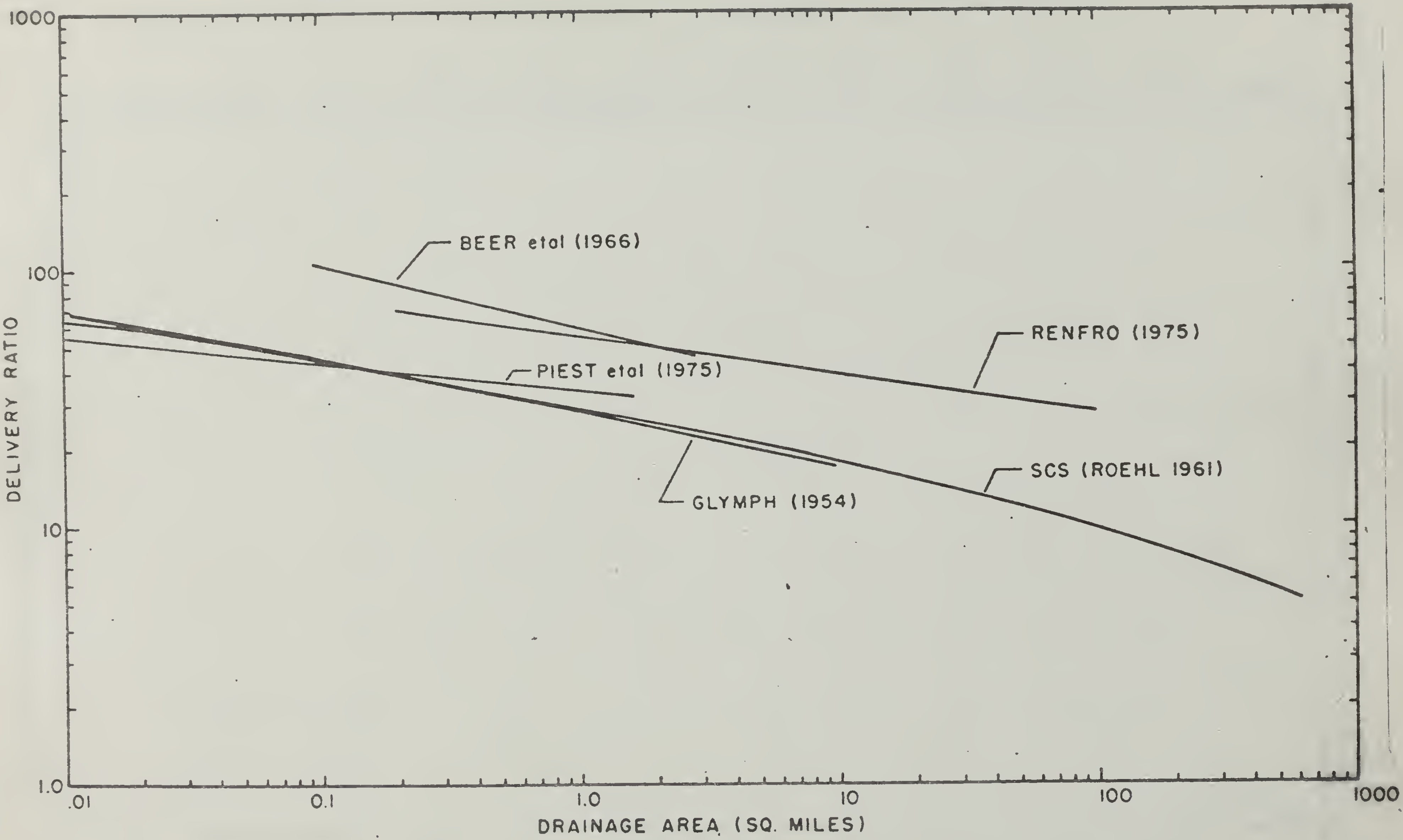


Figure 35. Sediment delivery ratio variations with drainage area as reported in the 1972 Sediment Yield Workshop (U.S. Dept. Agr., Agr. Res. Serv. S-40, 1975). (Multiply mi^2 by 2.59 to obtain km^2.

Yield Workshop (USDA-ARS, 1975). The SCS curve, which is based on widely scattered data, is probably the best to use in the absence of site specific data.

5. Map of soil detachability (erodability) using indexes from laboratory tests on field samples of soils.

Not available.

6. Estimates of sediment yields from unreclaimed spoils.

Not available (see item #8)

7. Estimates of effects of reclamation on sediment yield to time.

Not available.

8. Results of rainfall simulator studies on undisturbed areas and disturbed areas in the principal soil-plant communities of the region.

Infiltrometer sediment data are currently available from wide rangeland plant communities, mining sites, and geologic conditions, though none are from the specific report area. A listing of some of the available data are given in Tables 23 through 27.

Of great interest in this report is the ability to predict erosion losses. Triests (1977) has recently analyzed sediment data from 2,805 infiltrometer plots to determine whether the Universal Soil Loss Equation, a modified version of the original Musgrave Equation, or a modified version of the original Universal Soil Loss Equation could be used to predict erosional losses. Scatter diagrams showing various data sets are shown in Figures 36 through 41. The results showed that the three soil loss prediction equations are not universal, but for the most part, explain sediment yield with varying degrees of accuracy in different situations with no apparent trends or patterns. Best results were obtained on individual mine sites and other sites with loosely consolidated soil.

Table 23. Nevada rangeland communities for which erosion rate estimates are available (Trieste 1977).

Plant Community	Symbol
Black sagebrush/Shadscale saltbrush	SBS
Big sagebrush	BSG
Big sagebrush/rubber rabbitbrush	BSR
Douglas rabbitbrush	DRB
Douglas rabbitbrush/winterfat	DRW
Utah juniper	UJP
Single-leaf juniper/Utah juniper	PUJ
Big sagebrush/bluebunch wheatgrass/balsamroot	SWB
Big sagebrush/Sandberg bluegrass/phlox	SBP
Pinyon-juniper/low sagebrush/sandberg bluegrass	PJS
Crested wheatgrass	CWG
Big sagebrush/sandberg bluegrass/arrow leaf balsamroot	BSA
Pinyon-juniper/black sagebrush	PJB
Big sagebrush/snowberry	BSS
Snowberry/big sagebrush/bluebunch wheatgrass/wooly Wyethia	SSW

Table 24. Site characteristics for mined areas in Utah for which soil erosion data exist.

Mining Site	Symbol	% Soil > 2mm	Texture of Soil < 2mm	% Slope
Sampled in 1975				
Five Mile Pass	FMP	44	Clay loam	70 (16)[1]
Lewiston Canyon	LEW	--	Silt loam	21[2]
Golden Gate	GOL	36	Sandy loam	(2)
Silver City	SIL	56 (15)	Silt loam	73 (19)
Sunrise	SUN	70	Clay-sandy loam	68
Spor Mountain	SPR	63	Sandy loam	82
Brush Beryllium	BRU	18	Sandy lcay	55 (13)
Keystone Wallace	KYW	4	Silt loam	27
Old Hickory	OLD	58	Sandy loam	74
Bowana Copper	BOW	62	Sandy loam	5
Rattlesnake Ranch	RAT	21	Clay loam	61
Fry Canyon	FRY	22	Silt loam	88
White Canyon	WHT	60	Silt loam	68 (7)
Dutchman Flat	DUT	26	Silt loam to clay	61
Alta, Upper Emma	ALU	52	Sandy loam	64
Alta, Parking Lot	ALP	47	Sandy loam	74
Alta, Bel Vega	ALB	63	Silt loam	79
Pacific	PAC	57 (45)[2]	Sandy loam	65 (11)[2]
Stubbs Clay	STU	43	Silty clay	55 (13)
Mill Creek	MLC	63	Sandy loam	80
Kimberly, South	KMS	33	Sandy loam	16
Kimberly, North	KMN	33	Sandy loam	16
Box Creek Clay	BOX	43	Sandy clay loam	63 (14)[3]
Hiawatha	HIA	72	Sandy loam	9
Old Frisco	FRS	50 (39)[2]	Clay loam	76 (56)[2]
Castle Gate	CAS	45	Sandy loam	50
Stauffer, S.E.	STS	61	Clay loam	20
Stauffer, N.W.	STN	67	Loam	12
Sampled in 1976				
Five Mile Pass	FML	49	Silty clay	39
Mercur	MCR	0	Clay loam	10
Chief #1	CHF	68 (58)	Sandy loam	101
Scofield	SCO	44 (35)	Sandy clay loam	60 (5)
Joe's Valley	JOE	51	Loamy sand	60
Henifer	HEN	40	Sandy clay loam	72
Rock Candy Mtn.	RCM	61	Sandy loam	55
Marysvale	MAR	77 (50)	Sandy loam	63 (17)
Bullion Canyon	BUL	70	Sandy loam	58
Milford	MIL	45	Loamy sand	45
King David	KND	51	Sandy loam	55

Date from Burton (1976) and Thompson (1977). (Taken from Jaynes, 1977)

1. Numbers in parentheses apply to spoils topography designated as relatively "flat".
2. Tailings.
3. Stockpile.

Table 25. Site characteristics for mined areas in Utah.

Mining Site	Symbol	% Soil > 2mm	Texture of Soil < 2mm	% Slope
Geneva	GEN	58 (36)[1]	Sandy loam	59 (5)
Upper Marysvale	UPM	58	Sandy clay loam	54
Firefly	FRF	33	Sandy loam	66
Vanadium Queen	VAN	46	Sandy loam	79
Natural Bridges	NAT	41	Clay loam	59
Dog Valley	DOG	50	Sandy clay loam	78
Utah International	UTI	70 (75)	Sandy loam	81 (5)
Keefer Wallace	KEW	39 (49)	Sandy clay loam	48 (6)
Cedar City Canyon	CCC	44 (48)	Sandy loam	60 (5)

[1] Numbers in parentheses apply to spoils topography designated as relatively "flat".

[2] Tailings.

[3] Stockpile.

Table 26. List of locations of chained and unchained pinyon-juniper communities in central and southern Utah for which soil erosion estimates exist.

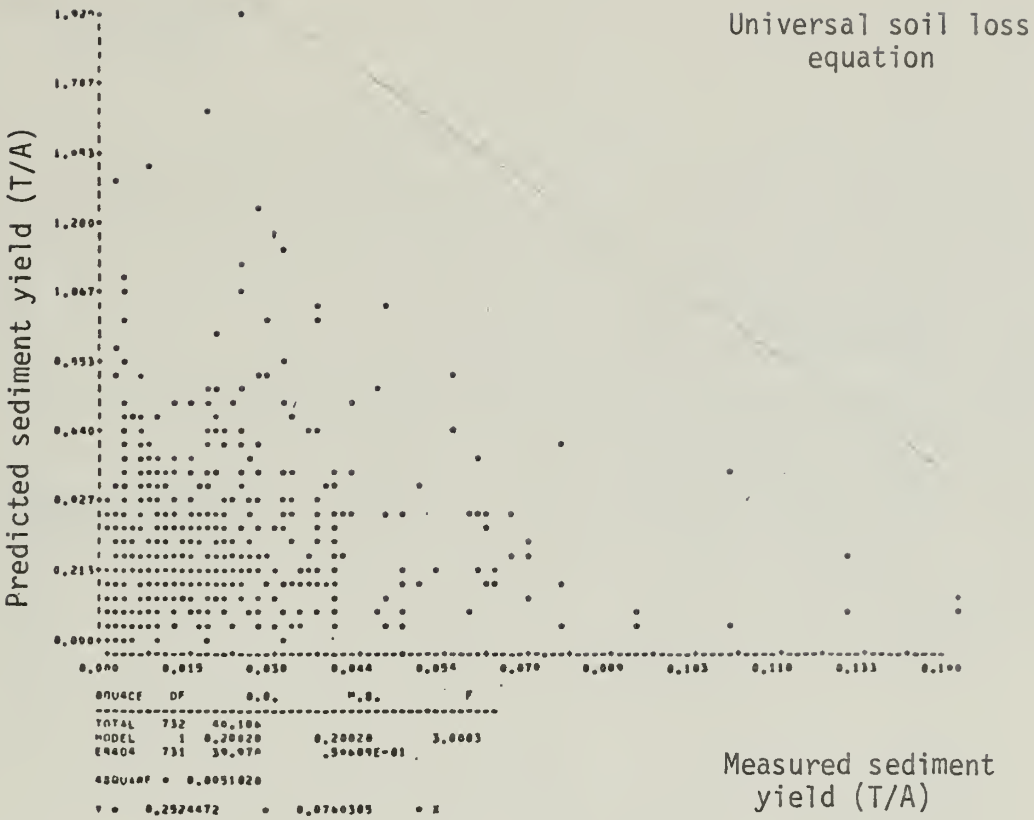
Location	Site	Symbol
Price	Pinnacle Bench	PB
	Coal Creek	CC
	Wood Hill	WH
	West Huntington	HN
Blanding	Brush Basin	BB
	Alkali Ridge	AR
	Area 149	149
Eureka	Boulter	BR
	Government Creek	GC
	Fry Canyon	FC
	Beaver	BR
Milford	Indian Peaks	IP
	Jockeys	JY
	Arrow Head Mine	AM

Data from Williams (1969)

Table 27. Different geologic types for which soil erosion data exist.

Geologic Type	Brief Description
A. Mancos shale members	
1. Masuk (M)	gray, marine shale
2. Blue gate (BG)	light, gray, calcareous marine shale
a. Upper BG (UBG)	
b. Middle BG (MBG)	
c. Lower BG (LBG)	
3. Tunuk (T)	gray marine siltstone and claystone
4. Mancos Undivided (MUD)	
B. Cedar Mountain (CM)	modular shale with fluvial sandstone beds
C. Alluvial Deposits (AD)	gravel surfaces, mainly terraces and pediments undergoing erosion
D. Gravel Caps (GC)	gravel surfaces
E. Black Hawk Fm (BH)	sandstones
F. Price River Fm (PR)	Series of interbedded sandstone and mudstone
G. North Horn Fm (NH)	Varigated shales with lenses of sandstone and fresh-water limestone
H. Colton Fm (C)	Fluvial red beds with channel sandstones
I. Green River Fm (GR)	Lacustrine shale and siltstone with numerous fossils and oil shale

Data from Ponce (1975)



```
SOURCE   DF      S.S.          M.S.          F
---------------------------------------------------
TOTAL    732   40.106
MODEL      1   0.20020       0.20020       3.6663
ERROR    731   39.906        .54609E-01

RSQUARE = 0.0051020

Y =   0.2524472   +   0.0760305   * X
```

Figure 36. Scatter diagrams for universal soil loss erosion prediction equation using data from Nevada rangeland (Nev.) study pooled over all plots.

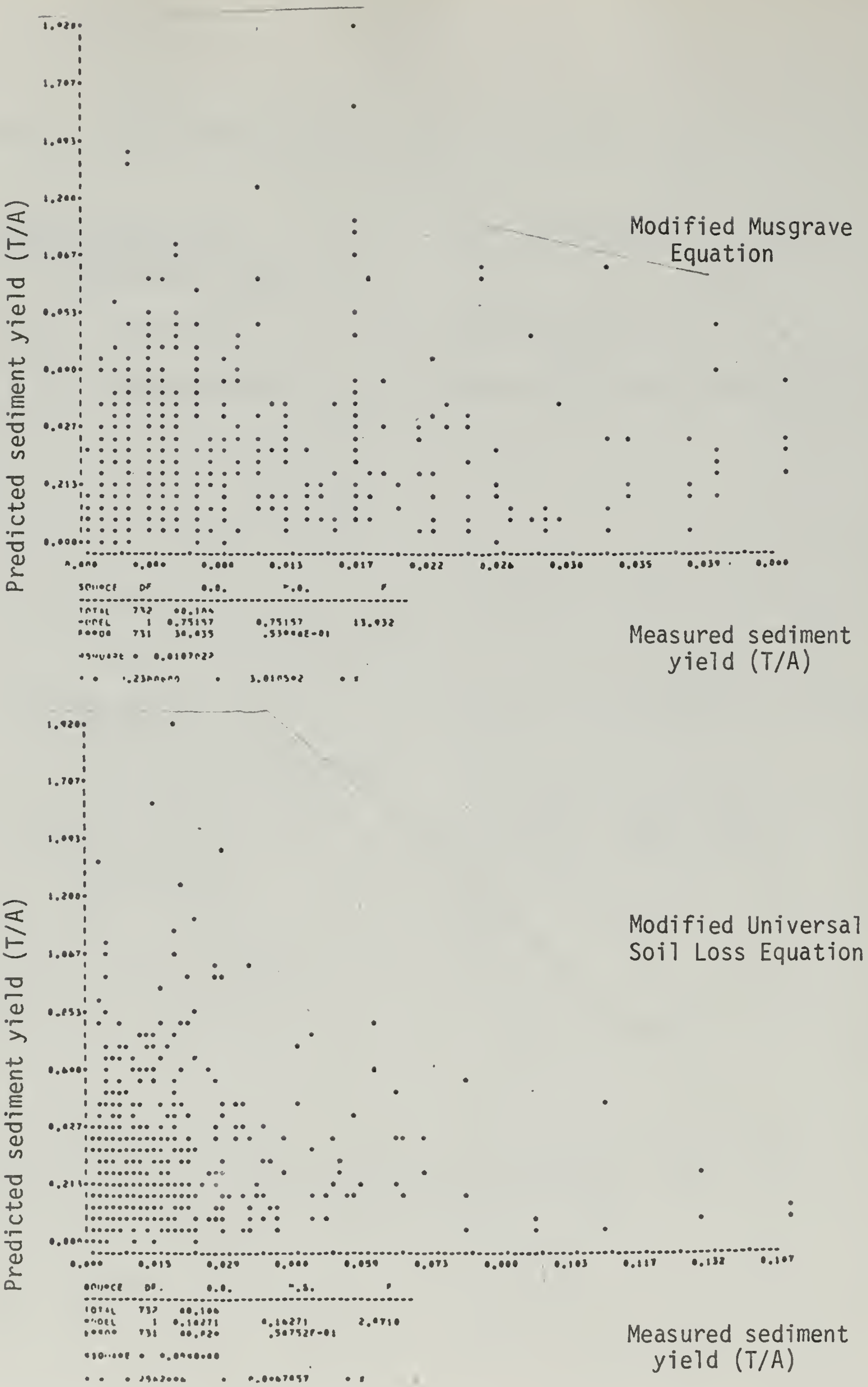


Figure 37. Scatter diagrams for two erosion predicting equations using data from Nevada rangeland (Nev.) study pooled over all plots.

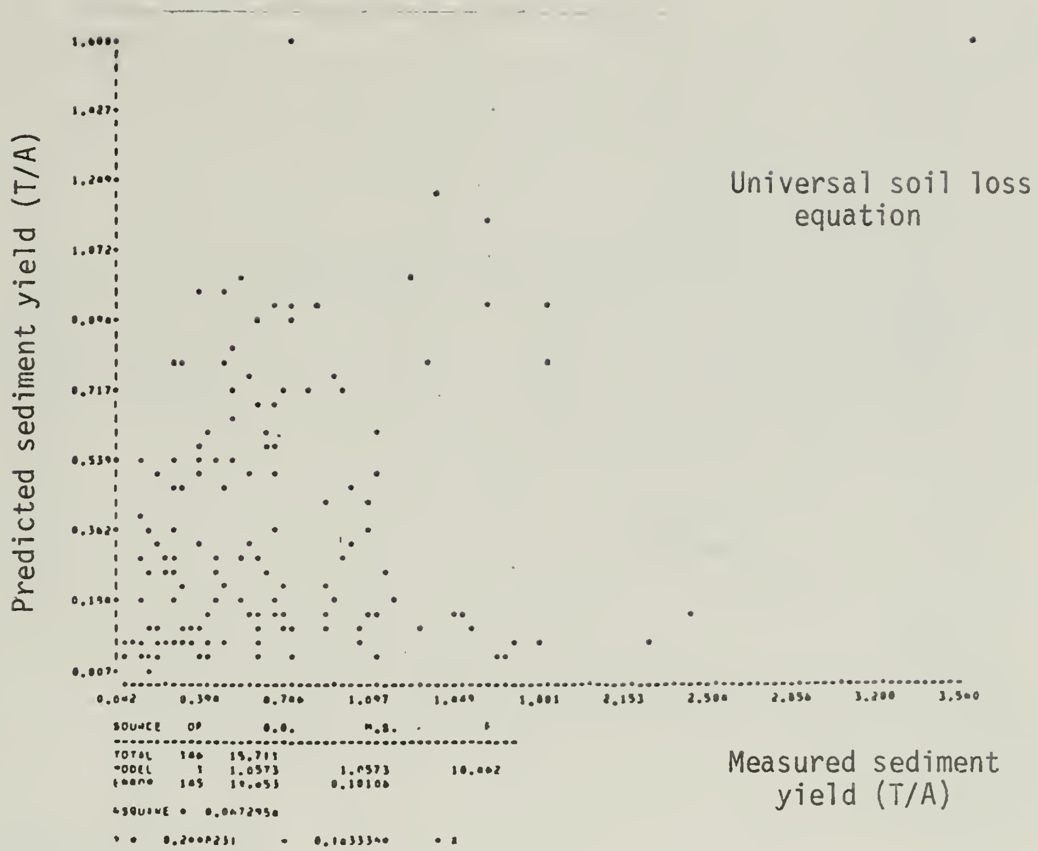
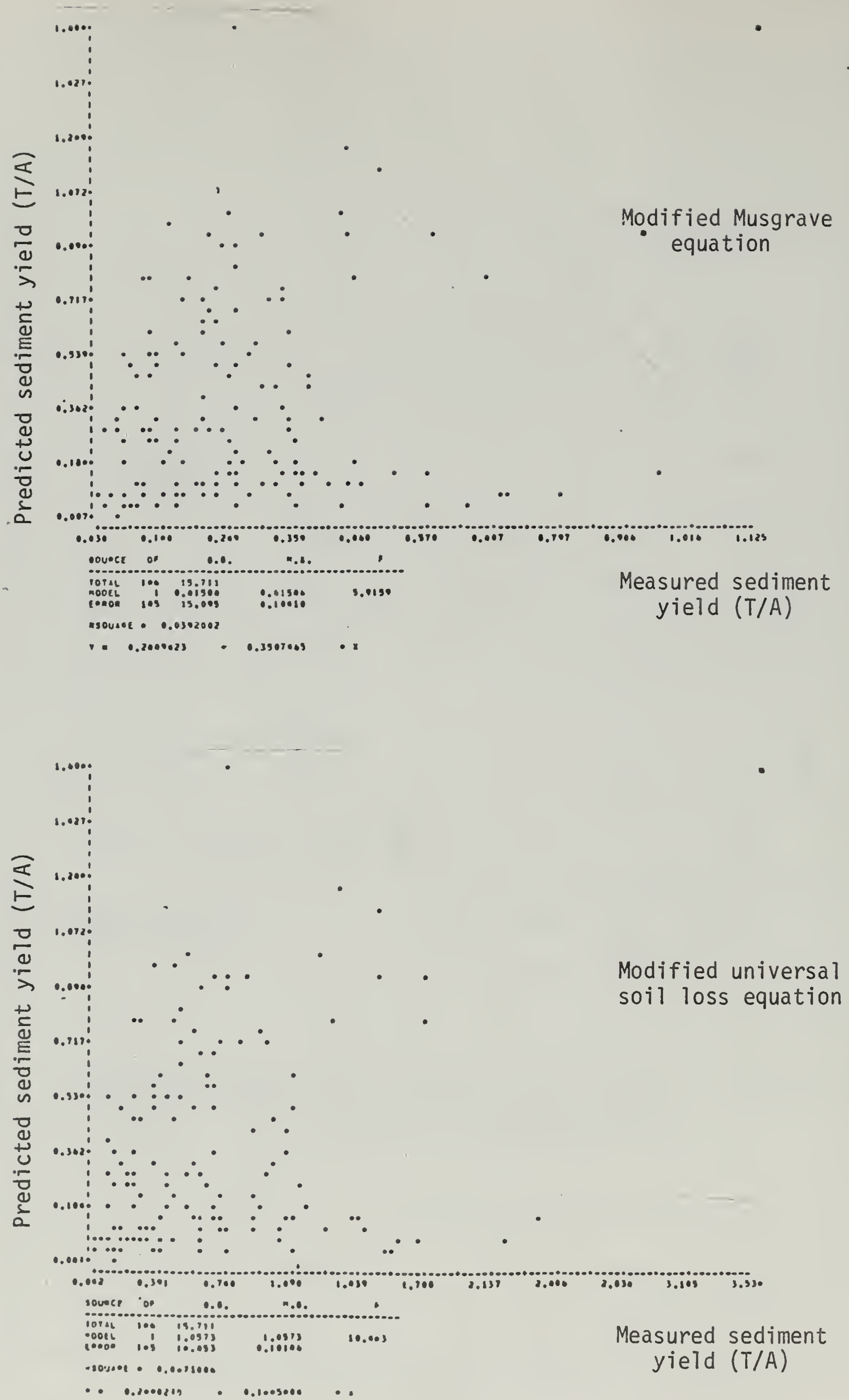


Figure 38. Scatter diagram for universal soil loss erosion prediction equation using data from geologic type study pooled over all plots.



```
SOURCE   DF      S.S.         M.S.        F
------------------------------------------------
TOTAL    106   15.711
MODEL      1   0.61500      0.61506     5.9159
ERROR    105   15.095       0.14410

RSQUARE = 0.0392002

Y = 0.2009623   +  0.3507465   * X
```

```
SOURCE   DF      S.S.         M.S.        F
------------------------------------------------
TOTAL    106   15.711
MODEL      1   1.0573       1.0573      10.463
ERROR    105   14.653       0.10106

RSQUARE = 0.0673006

Y = 0.2000219   +  0.1605006   * X
```

Figure 39. Scatter diagrams for two soil loss predicting equations using data from geologic type study pooled over all plots.

```
SOURCE    DF        S.S.          M.S.          F
-----------------------------------------------------
TOTAL    415    680.11
MODEL      1    53.488        53.488        35.626
ERROR    414    626.22        1.5126

RSQUARE =  0.0792350

Y =   0.4030025    *    1.920436    * X
```

Figure 40. Scatter diagram for universal soil loss erosion prediction equation using data from pinyon-juniper (chaining) study pooled over all plots.

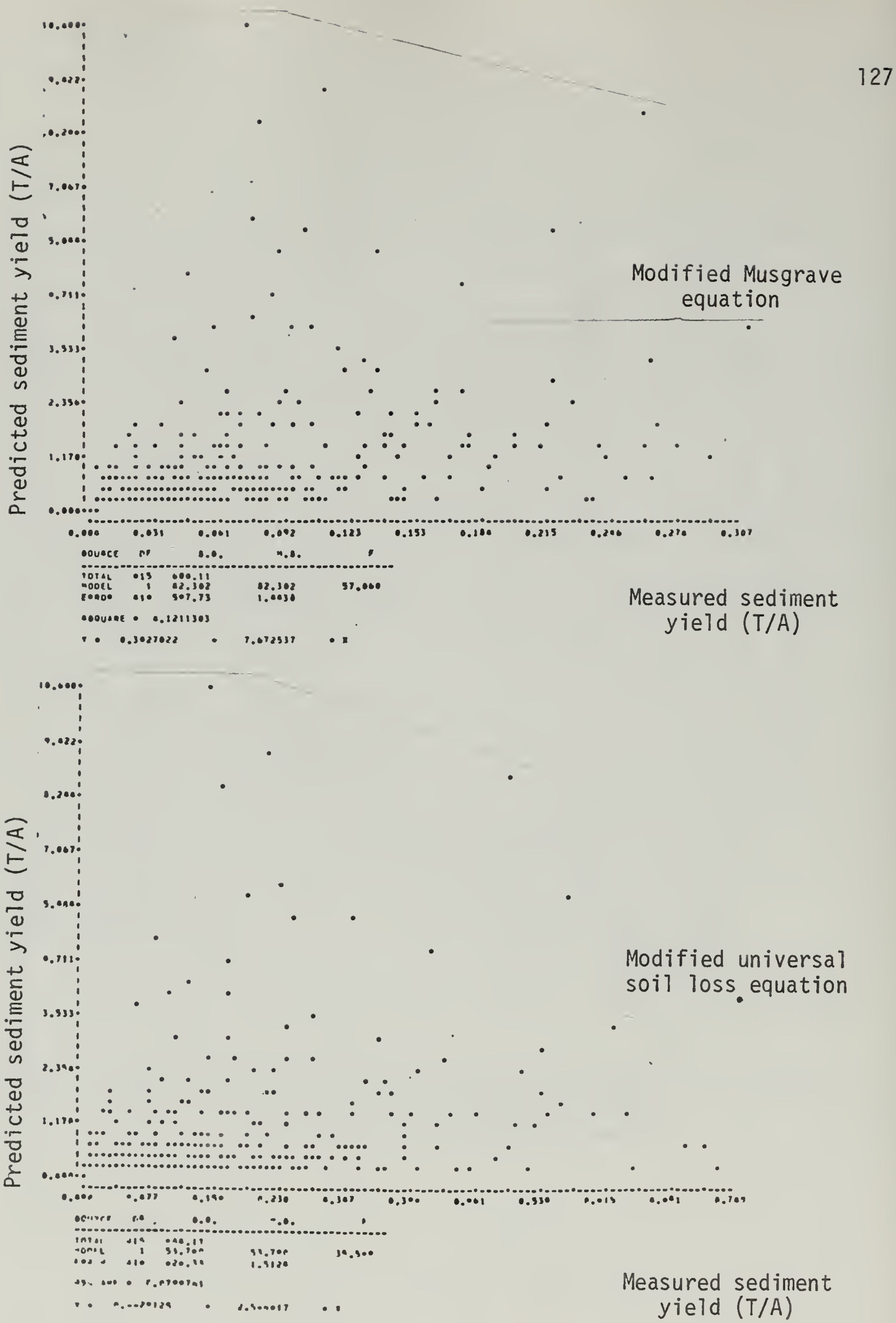


Figure 41. Scatter diagrams for two soil loss equations using data from pinyon-juniper (chaining) study pooled over all plots.

Little improvement was made in reducing the variability of the equations by placing exponents on each factor indicating that the factors, as determined in each equation, do not explain sediment yield under western rangeland conditions.

I. Hydrology and Water Supply

1. Surface waters (amount of water)

Perhaps the most pertinent report (in fact, the only study) on surface waters of the report area is that of Goode and Olson (1977). The following is extracted from their report.

> Sources of surface water that might supply some water for the coal basin include local streams, more distant sources such as Oak Creek and Pleasant Creek, both of which rise on Boulder Mountain to the west, and the Fremont River itself. All are subject to wide variations in discharge and much if not all the water has been appropriated or is subject to strong protest by holders of current rights.
>
> Measurements and estimates of discharge (1975-1977) of many streams that drain the Henry Mountains are given... The discharges observed in 1977 are all much lower than discharges observed in 1975 or 1976, and they serve as a warning that surface waters cannot be considered to be dependable sources of supply.
>
> Like all creeks in the Henry Mountains area, the creeks that drain the coal basin, principally Sweetwater Creek and its tributaries to the north and Bullfrog and Hansen Creeks and their tributaries to the south, are fed by snowmelt and springs in their headwaters, but are generally intermittent below about 5000 feet. In their lower reaches these streams are generally "dry except for short periods of flood immediately after local storms" (Hunt, 1953, p. 212). Thus the streams near the coal deposits are not likely to provide dependable supplies, although some of the springs that provide headwaters flow might be tapped...
>
> At the present time water from South and Dugout Creeks, tributaries to Sweetwater, is diverted for irrigation on the King Ranch. The amount diverted is now known, but estimates of the flows of these two creeks indicate that during spring and summer in years of normal precipitation they might yield about 2 cfs of water of good quality...

> Oak Creek and Pleasant Creek rise on Boulder Mountain west of the Waterpocket Fold and then flow eastward and northward to join the Fremont River. Water rights recorded by the State Engineer (Proposed Determination of Water Rights in Colorado River Drainage Area, Dirty Devil River Division, Pleasant Creek and Sandy Creek Subdivisions, no date) suggest that each of these creeks yields 7,000 to 10,000 acre-feet. But this water is diverted by holders of the rights, so that little water, except possibly from flash floods, flows from these creeks to the Fremont. We have a measurement of one diversion of 5 cfs from Oak Creek at the mouth of Oak Creek Canyon and spot estimates on Oak and Pleasant Creek... In addition, the U. S. Geological Survey measured Pleasant 0.2 mile above its confluence with the Fremont from March 1969 through September 1972 and recorded discharges of 3020 acre-feet in water year 1970, 2340 in 1971, and 1510 in 1972 (U. S. Geological Survey 1970, 1971, 1972)...
>
> The Fremont River discharged at Caneville an average of 67.1 cubic feet per second (cfs) for a total of 51,150 acre-feet per year from March 1967 through September 1974. Maximum discharge was 2310 cfs on August 27, 1971, and the minimum discharge was 11 cfs on August 13-15, 1972 (U. S. Geological Survey, 1975).

Since the above report included only very limited sampling, information on mean annual flows, long term water supply and flow durations, seasonal variations, and rare events is not available for this study area. General information on the Fremont and Dirty Devil rivers is available from the Utah Division of Water Resources (1975 and 1977, respectively).

2. Subsurface water

Goode and Olson (1977) indicate there are several waterbearing sandstones within the Henry Mountains area. These include, from oldest to youngest, the Wingate, Navajo, Entrada, Morrison, Dakota, Ferron, Emery, and Mesaverde. Within the project area, the unit with the greatest potential is probably the Navajo Sandstone, followed by the Entrada which yields only small quantities of water of poor or variable chemical quality in most areas. Thus the Navajo is probably the main source of groundwater. That little is known regarding probable groundwater reservoirs in southeastern Utah is emphasized in Figure 42; no reservoirs are mapped.

Water Yield: Bedrock generally yields water slowly to wells, but can yield water readily when the formation is fractured. Of 175 wells noted in the Paria-San Rafael Area Appraisal Report (U. S. Dept. of Interior, 1975), it was found that most wells discharge less than 50 gallons per minute, a few discharge as much as 250 gallons per minute, and very few discharge more than 450 gallons per minute (Table 28). Dry holes are common. In the lower Wahweap Creek area where the Navajo formation is exposed just below the surface, several wells have been drilled which reportedly yield several hundred gallons to more than 1,000 gallons per minute (USDI Bureau of Land Management, 1976). Therefore, it appears that the Navajo may yield from nothing to over 1,000 gpm, depending on location, with flow rates of about 50 gpm or less on most wells.

Goode and Olson (1977) indicate that any plan to develop water in the Navajo will likely raise several questions:

a. Is water in the Navajo stagnant, or is it moving from recharge areas? How fresh is the water?

b. Will quantities pumped be matched by recharge?

c. What effect will pumping have on recharge or discharge area?

They briefly answer the questions as follows:

a. Water in the Navajo probably is not stagnant in most places. Its freshness in the Shootaring Well (southwest of the Henry Mountains) suggest closeness to recharge and perhaps relatively rapid movement in particular areas.

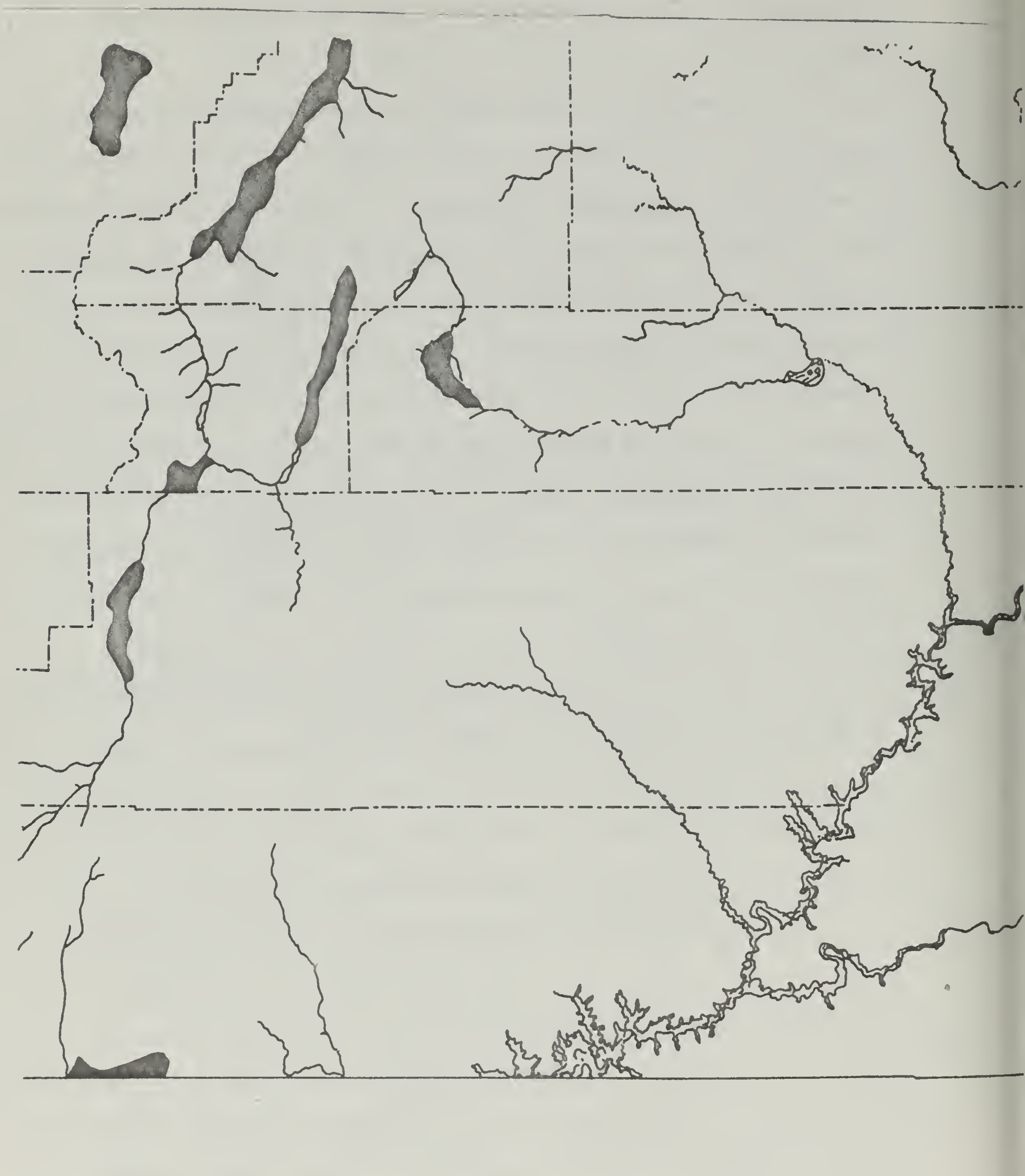


Figure 42. Known and probable groundwater resources in South Central Utah. (From Jeppson, et al., 1968.)

Table 28. Records of selected wells that draw water from Navajo sandstone, Henry Mountains area.

Owner	Local Number[1]	Station Number	Depth Drilled Feet	Depth Of Well Feet	Casing Diameter Inches	Depth Cases	Depth To First Opening	Depth To Aquifer
US BLM (USGS #3)	(D29-12)33ACD - 2	381440110362801	501	--	--	--	0	210
Weaver, Robert	(D31- 7)36DAD - 1S	380354111044602	6648	2305	10.75	2305	580	580
Poison Well (US BLM)	(D31-12) 4BDB - 1	380859110354801	--	450	--	--	--	--
Shitamaring Mine	(D35-11)16DCD - 1	374531110420001	--	1000	8.00	--	--	--
Romex No. 1 Fed.	(D36-10)21BDB - 1	374000110491501	3043	--	4.50	3043	2996	--

	Principal Aquifer	Altitude Land Surface	Water Level Feet[2]	Discharge GPM[3]	Draw Down Feet	Specific Gravity GPM/ft	Pumping Period Hours	Date Of Completion	Of Use Water
US BLM (USGS #3)	220NVJO	4616	140.90	200	--	--	8.0	8-10-76	
Weaver, Robert	220NVJO	5361	305.00	55	--	--	--	1969	IRR, CUL, STK
Poison Well (US BLM)	220NVJO	4900	--	12	--	--	--	1958	STOCK
Shitamaring Mine	220NVJO		140.00	75	--	--	Cont.	1976	IND, CUL
Romex No. 1 Fed.	220NVJO	3956	F	350	--	--	--	8-18-69	UNUSED

1. Codes indicate: D, deepened; S, plugged back; 1, first well; 2, second well on the ten-acre tract.
2. Measured in feet below land surface. Measurements followed by + are above land surface. F indicates a flowing well. G indicates use of pressure gage.
3. Discharge followed by F indicates a flowing well.

From Goode and Olson (1977)

b. Because wells pumped in the coal basin probably will be many miles from recharge, it is likely that water pumped for the first few years will come from storage and that recharge areas will not be affected for a long time.

c. The effect pumping may have on natural discharge areas is unknown because those areas themselves are unknown. The effect of pumping on recharge areas is covered in "b" above.

Water Quality: Goode and Olson (1977) indicate that water drawn from the Navajo Sandstone falls into two categories: that with dissolved solids in the range of 933 to 4,200 ppm, and dissolved solids in the range of 188 to 442 ppm. Wells north of the Fremont River are in the former category, whereas five wells scattered among five townships (Table 29), from 29 to 36 south, on both sides of the Henry Mountains, are in the latter category. Chemical analyses of the five wells pertinent to the report area are given below in terms of a range of values sampled.

3. Effects of mining on area hydrology.

So little is known regarding the natural hydrology of the project area that it is difficult to determine the effects of mining. The following generalizations may be relevant:

a. Lack of vegetation on strip mine spoils will make it vulnerable to wind and water erosion processes.

b. Quality of surface runoff waters will be altered.

c. Due to high evaporation potentials, it seems unlikely that on-site precipitation would ever significantly contribute to the ground reservoir. Possible effects of mining on aquifers, springs, and wells cannot be determined at this time.

d. Continuing water studies related to the study area are needed.

Table 29. Chemical analyses of five wells in Henry Mountains showing the range of values reported.

Temperature (^{o}C)	16.5	-	21.0	
Dissolved silica (SiO)	9.6	-	15.0	mg/l
Dissolved calcium (Ca)	13.	-	59	mg/l
Dissolved magnesium (Mg)	11.	-	42	mg/l
Dissolved sodium (Na)	6.5	-	55	mg/l
Dissolved potassium (K)	2.0	-	7.5	mg/l
Bicarbonate (HCO_3)	110.	-	245	mg/l
pH	7.1	-	8.5	
Dissolved sulphate (SO_4)	27	-	229	mg/l
Dissolved chloride (Cl)	2.8	-	15	mg/l
Dissolved nitrite plus nitrate (N)	.01	-	.73	mg/l
Dissolved fluoride (F)	.1		.3	mg/l
Dissolved orthorphosphorus (P)	.00	-	.01	mg/l
Dissolved orthorphosphate (PO)	.00	-	.03	mg/l
Dissolved boron (B)	30	-	150	mg/l
Dissolved arsenic (As)	0	-	5	mg/l
Dissolved lead (Pb)	4	-	12	mg/l
Dissolved lithium (Li)	20	-	80	mg/l
Dissolved zinc (Zn)	20	-	560	mg/l
Dissolved solids	188	-	442	mg/l
Specific conductance	350	-	640	micromhos
Hardness (Ca + Mg)	78	-	296	mg/l
Noncarbonate hardness	0	-	206	mg/l
Sodium absorption ratio	.2	0	2.7	

e. Recommendations for additional study needs include the followin

Since no site-specific study has been attempted, almost any study would be helpful. Since most of the mining impacts will occur with respect to surficial hydrology, it would appear useful to establish some baseline infiltrometer studies to ascertain infiltration characteristics, erosion potentials, and possible water quality problems. It may also be worthwhile to establish some small baseline watersheds, some of which would be mined at a later date. Emphasis would be placed on surface flows and on water quality (especially sediment and total dissolved solids) of small watersheds.

f. Evaluation of available water supply for use in revegetation and reclamation of the study area.

Some estimate of the water available for revegetation and reclamation can be ascertained from Goode and Olson (1977). Their conclusions are as follows:

> Observations during the 1975 and 1976 field seasons, after winters of normal precipitation, and during the 1977 field season, after a dry winter, confirm that springs and the mountain streams fed by them cannot be depended upon as water supplies. Therefore any major development of coal will have to depend on water from underground supplies.
>
> The water requirements for major development of coal would include 100 to 150 gallons per day per person, water for plant maintenance and revegetation of perhaps 1000 acre-feet per year, plus water for the [particular] kind of coal development...
>
> Water to meet these requirements may be available from the following sources:
>
> (1) In years of normal or excessive precipitation, water [may be obtained] from springs by pipeline in amounts of 200 to 400 acre-feet per year. Measurements of springs after the dry winter of 1976-77 prove that springs are not dependable and therefore any use dependent on springs would require a back-up source of water.

(2) Water from the Navajo Sandstone might support properly-spaced wells in a field that would yield 20,000 to 30,000 acre-feet per year. Water from the Navajo in this and other areas may be of excellent to poor chemical quality and thus may require treatment before use.

(3) Water from shallow aquifers such as the Mesaverde, Emery, Ferron, Morrison, or Entrada might supply limited quantities of perhaps 2,000 to 3,000 acre-feet per year. Water samples collected from these formations during this investigation suggest that water from these sources is of poor or variable chemical quality and therefore may require treatment before it can be used.

(4) Water imported from Oak Creek and/or Pleasant Creek might supply 2,000 to 3,000 acre-feet per year if water rights can be purchased from present owners. Although these creeks were not looked at in 1977, it is likely that the general drought caused both to have low flow: likely these sources of water would be no more dependable than the springs in the Henry Mountains.

4. Moisture Penetration Characteristics

Depth of moisture penetration in reconstituted spoil materials will be a function of storm characteristics, slope, spoil or soil texture, bulk density and any other factors which may influence soil permeability. Of most importance is the question of whether a potential exists for water to enter the "soil" and if that potential can be represented in terms of measured infiltration rates. Since reconstituted spoil piles are not available at this time, infiltration rates measured on naturally occurring geologic soil types may serve as a guide to infiltration rates to be expected on reconstituted spoil materials (Table 30).

As might be expected there is considerable variability, even within various members of the Mancos shale. Given the rainfall intensity pattern for a storm and assuming an approximate infiltration rate then

Table 30. Infiltration rates (f_c) by geologic-soil types. 28 minute infiltrometer runs of 2 1/2 ft.^{2} plots, summer, 1975 in the Price River Basin, Utah.

Geologic/Soil Strata	# Sites	# Plots	f_c (cm/hr)[2] $\bar{x}$	s
Masuk[1]	2	11	4.74	1.85
Upper Blue Gate[1]	4	24	2.67	1.61
Middle Blue Gate[1]	2	12	2.11	0.61
Lower Blue Gate[1]	2	12	1.40	0.68
Tununk[1]	3	18	2.45	0.68
Mancos Undiv.[1]	3	7	1.72	0.56
Cedar Mountains	2	12	2.04	0.81
Alluvium	2	12	3.61	1.99
Gravel Cap	2	12	4.11	1.23
Black Hawk	1	3	6.56	0.85
Price River	2	6	1.55	0.20
North Horn	2	6	1.52	0.24
Colton	2	6	1.69	0.14
Green River	2	6	2.54	0.53
TOTALS	31	157		

1. Mancos shale members

From Hawkins, Gifford, and Jurinak (1977).

2. f_c denotes rather constant infiltration rates at the end of a 28-minute infiltrometer run. All measurements were taken with a Rocky Mountain Infiltrometer.

the quantity of water which infiltrates the soil may be approximated. Depth of penetration is difficult to estimate, but may be approximated by knowing the antecedent soil moisture conditions and the total water holding capacity of the soil per unit depth, and then adding the precipitation which infiltrates the soil. Since sandy soils are not capable of holding much water per unit depth, an inch of water will penetrate much further into a sandy profile than into a clay profile which has the capability for holding considerably more water. One might, therefore, expect small storms to be somewhat beneficial to plants growing on sandy soils while on clay soils most of the water would be retained near the soil surface and therefore more susceptible to evaporation. However, for storing winter precipitation within easy reach of seedlings, a clay soil might be better than a sandy soil. Obviously any rehabilitation scheme should consider soil profile reconstruction in conjunction with prevailing precipitation trends.

J. Wildlife

General nature of wildlife habitats of the area

Because of the variations in elevation in the Henry Mountain area (4,700-11,500 feet), the habitats range from subalpine to desert grassland. The description of the major habitat types is listed elsewhere in this report and also in Stanton (1931). (Scientific names of animal species of the Henry Mountains Resource area are listed in the appendix).

1. Major habitat types of this area for wildlife are listed below with typical or important animal species of each.

a. Spruce-fir area. This habitat occurs primarily on the north facing slopes at higher elevations. Principal animal species present: mule deer, bison, bobcat, mountain lion, coyote, weasel, porcupine, chickaree (squirrel), chipmunk, deer mice, woodpecker, grouse, mourning dove, great horned owl, flicker, hairy woodpecker, Cooper's hawk, and goshawk.

b. Ponderosa pine area. This habitat is located on the west side of the Henry Mountain range. Some of the principal species found include: bison, mule deer, lion, bobcat, coyote, fox, chickaree, Cooper's hawk, goshawk, sharp-shinned hawk, screech owl, magpie, woodpecker, grouse, mourning dove.

c. Pinyon-juniper areas. This habitat covers a big portion of the Henry Mountain range. Common animal species of this area include bison, mule deer, lion, bobcat, coyote, fox, jack rabbit, cottontail rabbit, rock squirrel, porcupine, turkey vulture, golden eagle, kestrel, red-tailed hawk, prairie falcon, chukar, mourning dove, jay, magpie, crow, raven, robin, rattlesnake, and gopher snake.

d. Desert habitat. Although a few juniper are found in this area, the principal plant species include grasses, shadscale, greasewood, and Mormon tea. In this area there are bison, coyote, fox, kangaroo rat, golden eagle, turkey vulture, red-tailed hawk, prairie falcon, rattlesnake, gopher snake and lizards.

e. Reseeded areas. The reseeded areas constitute a large portion of the west slopes of the Henry Mountains. Most of the reseeded areas are those that were once pinyon-juniper. At present, these areas have a wheatgrass with various browse plants, planted specifically for big game animals. These areas are used heavily by domestic cattle, bison, mule deer, rabbit and various species of birds.

2. Some important wildlife species of the Henry Mountains.

a. Bison: The bison are a highly mobile and "spooky" species. They may be on Cave Flat one day and could move to Bull Creek Pass by the next day, a distance of over 20 miles. The primary range for the bison here is on the north mountain and adjacent areas. This includes Cave Flats, Tarantula Mesa, Airplane Springs, the Horn area, and about any place on the north mountain (Nelson, 1965). The present herd is estimated at 200 plus animals. A limited hunt is held on the Henry Mountains each year (10 permits in 1977).

b. Deer: Most of the deer are located in the pinyon-juniper, ponderosa pine, spruce, and fir areas, almost all areas on the mountain above the desert floor. A restricted hunt is held each year for mule deer bucks with more than three point antlers. The Henry Mountains make up a major portion of deer herd unit 52 as designated by the Utah Division of Wildlife Resources. In this herd unit there is 14,600 acres from which 292 deer were harvested in 1976.

c. Mountain lion: A small population of mountain lions is thought to occur over the entire Henry Mountain range. At the present time, this is a protected species in the Henry Mountains.

3. Endangered species.

No endangered species of wildlife are known to be on the Henry Mountains. The closest relevant citings of endangered wildlife found near this mountain range is a possible sighting of a black-footed ferret 75 miles to the north, and a possible nest of the peregrine falcon in Capitol Reef National Park. The nesting area would be at least 30 air miles from the north mountain section of the Henry Mountains. These two areas are separated by desert areas and the Waterpocket Fold.

K. Cultural

Cultural resources of the Henry Mountains area are limited by a small, rural population. Schools and churches provide a focus for social and cultural activities. Towns with a population of 100 or more generally have an elementary school and a church. Older children are bussed to a secondary school in the town of Bicknell. The predominant church - the Church of Jesus Christ of Latter Day Saints (Mormon) - serves many of the cultural needs of families who have lived in the area for generations.

The presence of Capitol Reef National Park with its information center and lectures serves as a stimulus for cultural awareness in the field of natural resources environmental quality, and earth science. Many visitors to the park and recreation resources on Lake Powell bring new attitudes and different cultural values. Successful rehabilitation following any surface mining activities in the region is imperative in view of the heightened awareness of environmental quality generated by activities at the National Park.

L. Archaeology

Seventy-two previously recorded archeological sites in the Henry Mountain resource area were restudied in 1977 (Worthington, 1977). Many sites could not be located because of poor directions, lack of legal description, or disappearance. Because of a combination of these factors, only 42 of the 72 sites were located and positively identified. Few sites remain untouched by modern man. Degrees of erosion and vandalism have taken their toll. Vehicle traffic into back country areas varies greatly depending on access from good roads. In 1975 the average traffic count on Highway 95 south from Hanksville was 290 vehicles per day with 220 apparently continuing on to Bullfrog Marina. The number of vehicles going south on the dirt road to Notom was 100 per day, with a daily average of five observed in the far south region of Star Springs. With only five vehicles per day in such remote areas this represents a potentially great impact on the continued existence of archaeological sites.

Sites are located in environments ranging from the high mountains to pinyon-juniper covered foothills and surrounding deserts. Five types of sites were surveyed: rock art (pictographs), lithic scatter (a stone tool chipping area), granary (walled storage structure), campsite and habitation (a structure under a rock overhang or a pithouse). Eight sites of importance on the west side of the Henry Mountains but generally east of the coal fields were described in the Worthington (1977) report.

M. Visual Prominence

Visual prominence may be defined as the degree to which given points, areas, or features in the landscape may be seen from any given observation point. The assessment of visual prominence provides significant information which can be evaluated to determine potential visual impacts for an area approximately 300 square miles that may result from proposed mining operations. The assessment of visual prominence is a function of three basic parameters:

1. topographic elevation of the observation point;
2. topographic elevation of the landscape point or area being viewed, and
3. topographic characteristics between the observation point and the landscape point or area being viewed.

The evaluation of these visual prominence parameters was accomplished through the use of the VIEWS computer program, a visual-search designed to analyze a topographic surface to determine the areas which can be seen from a certain point or points. Essentially, it determines those cells within the study area which are visible from a particular viewer position along a specified viewer radius. To accomplish the program tasks, the 300 square mile site was gridded into 60 acre cells. Each of these 60 acre cells was assigned a central elevation as interpolated from USGS 15 minute series maps.

Twelve observations positions were established as a means of determining the visual prominence of potential coal extraction sites (Figure 43). Four of these observer positions were located along the secondary road that proceeds southward from Notom, Utah; the remaining eight observer positions were located at potential extraction sites. Visual access is a function of linear vision; if a point or area can be seen from the observer position, then the observer position is also visible from that point or area in the landscape. The graphic printouts (Figures 44-49 and Appendix D) of the VIEWS program indicate those areas that can be seen from the identified observation points as a blackened area. These areas that cannot be seen from the observation points are shown as small crosses.

The figures illustrate visual prominence assessment for the twelve observer positions as indicated by figure 43.

Legend for considering visibility:

\+ = inside the search radius

■ = visible from the point

0 = viewing point

Because the coal extraction process requires the use of larger equipment such as high cranes and booms, each of the twelve positions has been evaluated in terms of visual prominence at eye level height (5'0"), as well as at an assumed boom height of 50'0; this provided

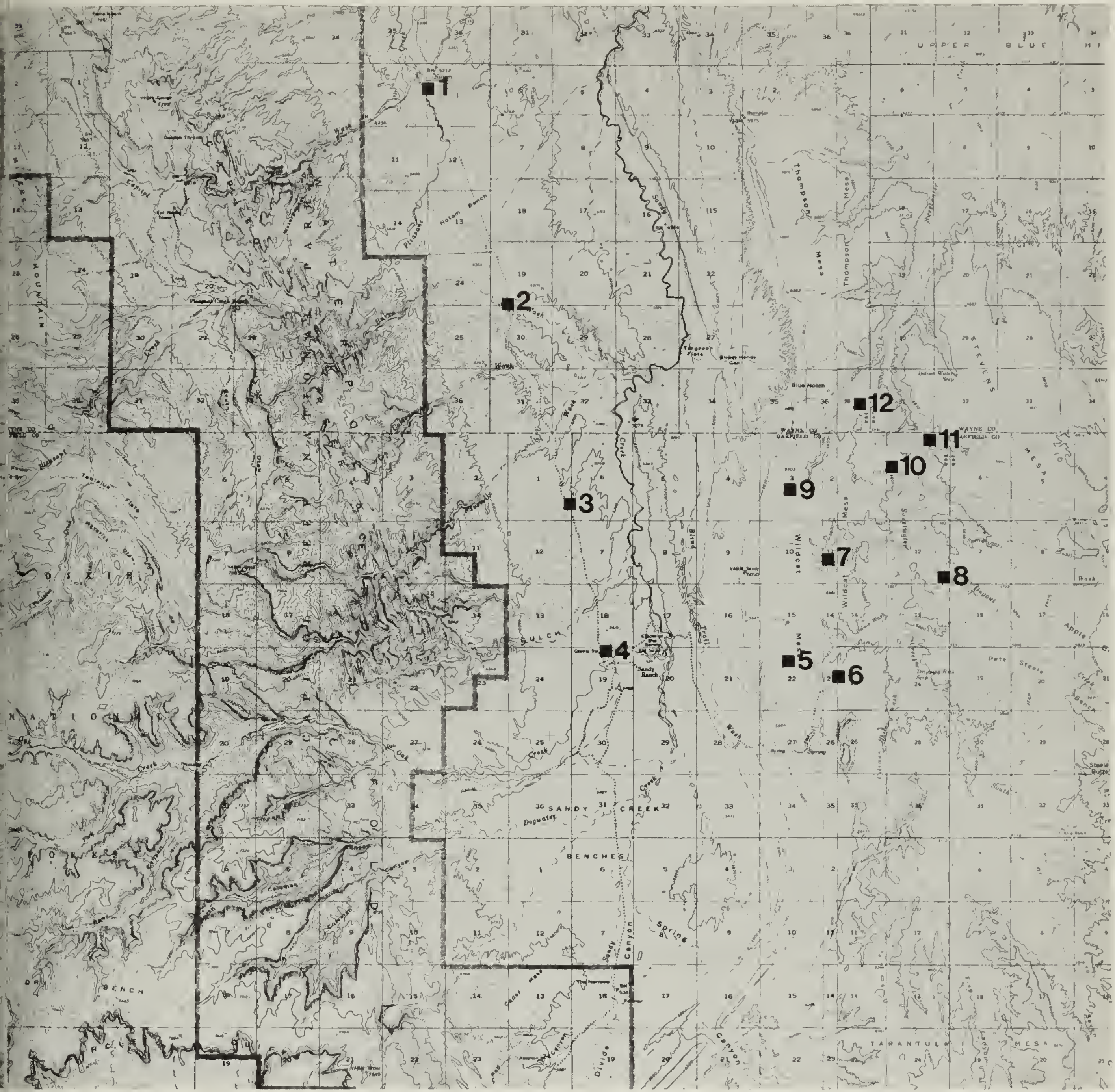


Figure 43. Map illustrating observation point locations within the 300 square mile visual prominence assessment area. Computer map of visibility points 9, 10, and 12 may be found in the following pages. Points 1, 2, 3, 4, 5, 6, 7, 8, and 11 are included in the appendix.

the opportunity to determine visual prominence of the existing topography, as well as to project the visual prominence of equipment with 50'0" heights.

Due to the geographic proximity of the potential extraction sites to the Capitol Reef National Park, this study has included visual prominence assessment of approximately 65 square miles within the Capitol Reef National Park. The visual prominence of potential extraction sites may be evaluated in terms of observer positions anywhere within this 65 square mile area. Areas of the Dixie National Forest were not evaluated for visual prominence from the proposed extraction sites because of adjacent topographic enclosure and the physical length of associated views. All indications suggest that visual prominence would be minimal, if not negligible.

The potential visual prominence of the extraction sites from observer positions within the Henry Mountain range were not included in the computerized study. The visual distances between the potential extraction sites and the Henry Mountain range (30-35 miles) are so great that the degree of visual resolution would be negligible.

An assessment of visual prominence indicates that the most of potential extraction sites are visually inaccessible from those areas of Capitol Reef National Park included in this study. Observation points 9, 10 and 12 may be seen from portions of Capitol Reef National Park. While observation point 9 at eye level viewing height (Figure 44) is visually inaccessible from Capitol Reef National Park study area, observation point No. 9 at a 50 foot viewing height (Figure 45) is visually accessible from twenty-five, 60 acre cells. This indicates the possibility of viewing portions of booms or cranes that are at

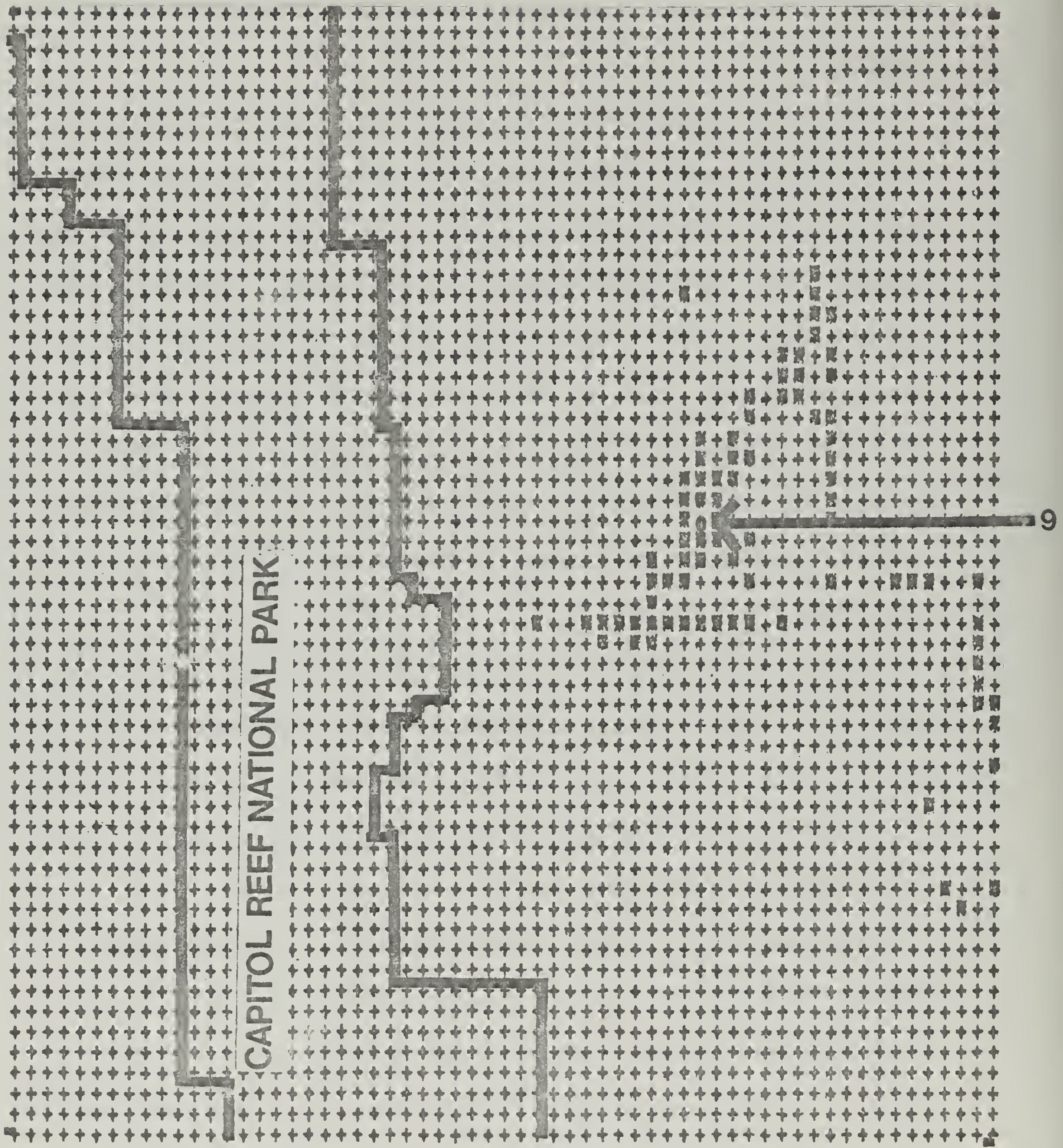


Figure 44. Observation point number 9: eye level viewing height.

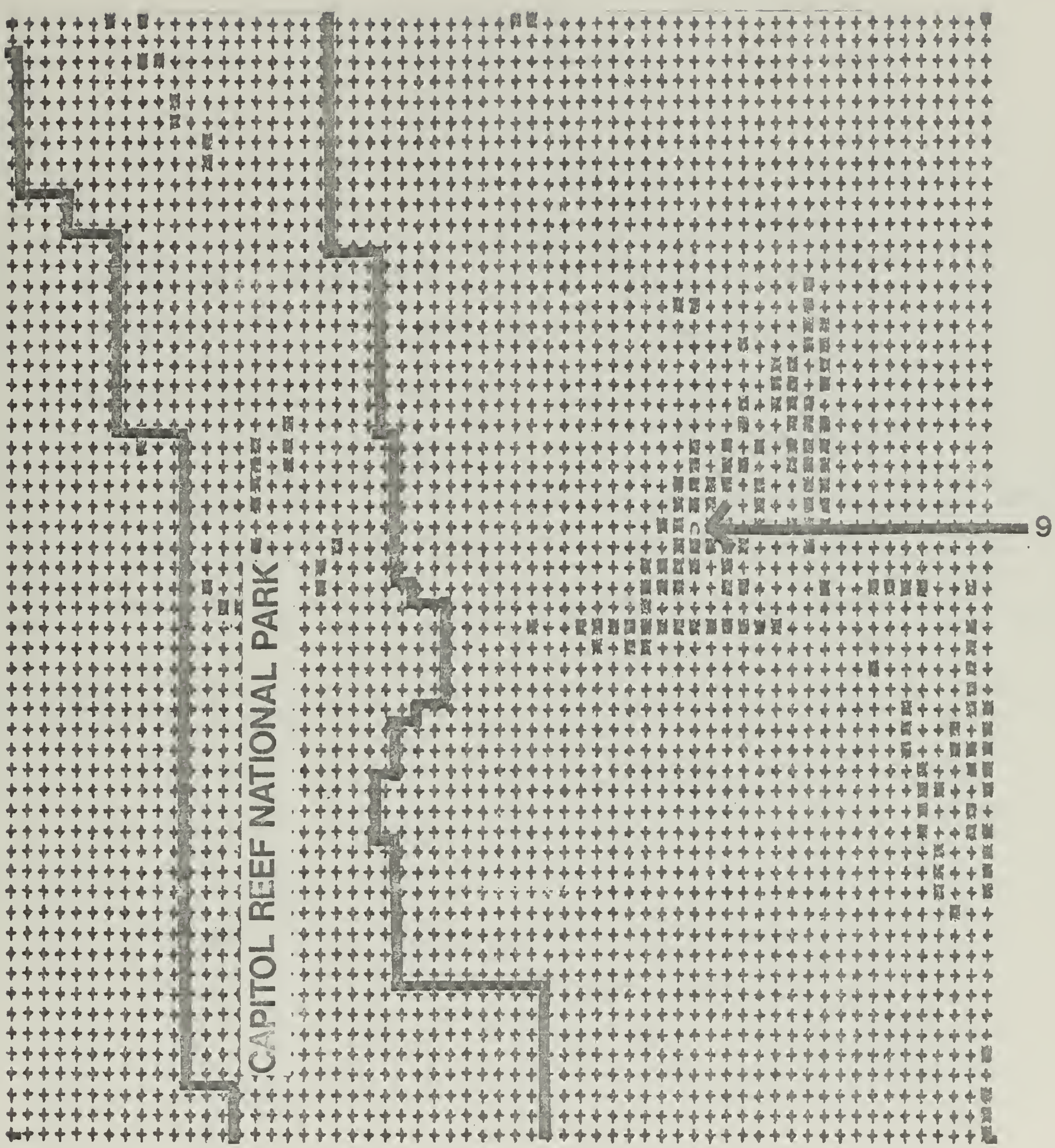


Figure 45. Observation point number 9: 50 foot viewing height.

heights of fifty feet or greater above the natural terrain.

Observation point No. 10, at eye level viewing height (Figure 46) is visually accessible from fifty, 60 acre cells from the Capitol Reef National Park study area. Observation point No. 10 at a 50 foot viewing height (Figure 47) is visually accessible from ninety-four, 60 acre cells from the Capitol Reef study area.

Observation point No. 12 at eye level viewing height (Figure 48) is visually accessible from eighty-three, 60 acre cells from the Capitol Reef study area, while the same observation point with a fifty foot viewing height (Figure 49) is visually accessible from one-hundred and fifteen, 60 acre cells from the Capitol Reef study area.

These three observations points (9, 10, 12) are located on the westernmost portions of Wildcat Mesa. The points also represent the highest elevations on these plateau formations.

While observation points 9, 10, and 12 are visually accessible from the study area within Capitol Reef National Park, the views generally occur over a 6-10 mile viewing distance and should be considered minimal in visual consequence. Planning for mining and operations must consider the visual accessibility of observation points. Operational structures, roadways, and other mining-related facilities should be located to avoid visually prominent areas. Future studies should also be undertaken to ascertain the projected growth of public use in areas of Capitol Reef National park that has direct observation points for the mining operations.

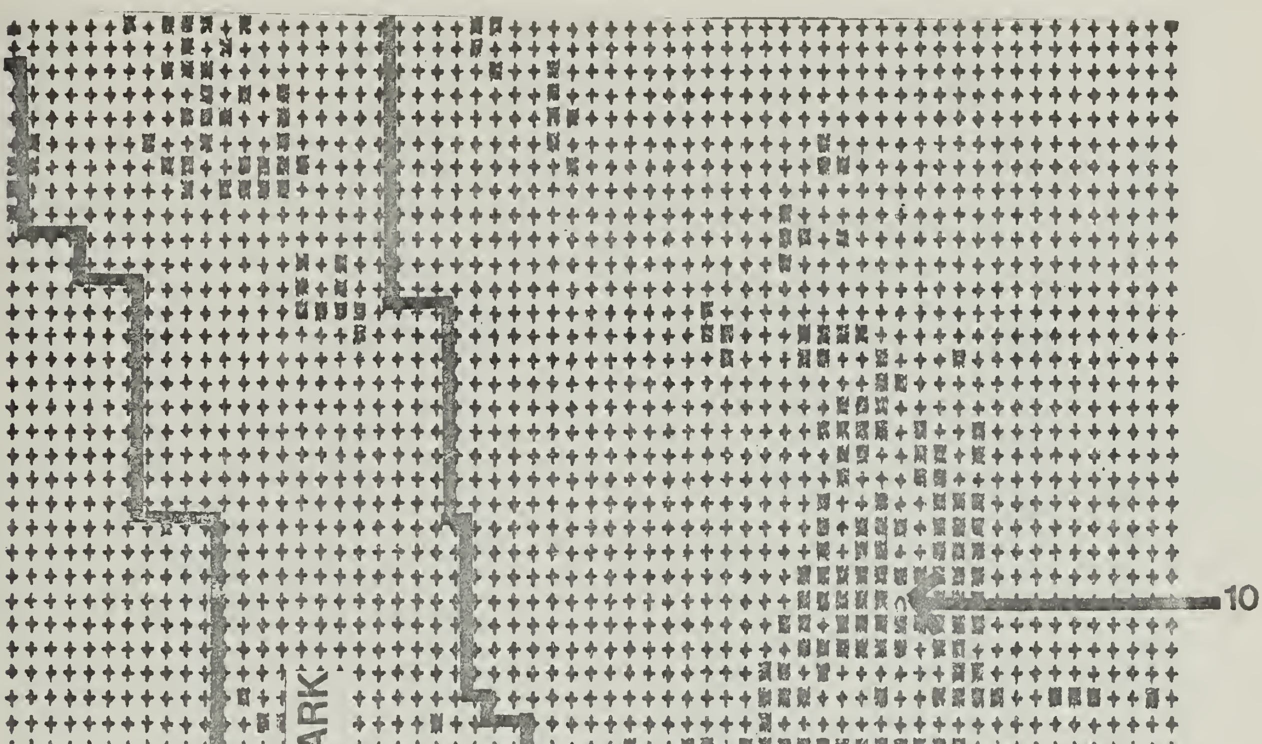


Figure 46. Observation point number 10: eye level viewing height.

Figure 47. Observation point number 10: 50 foot viewing height.

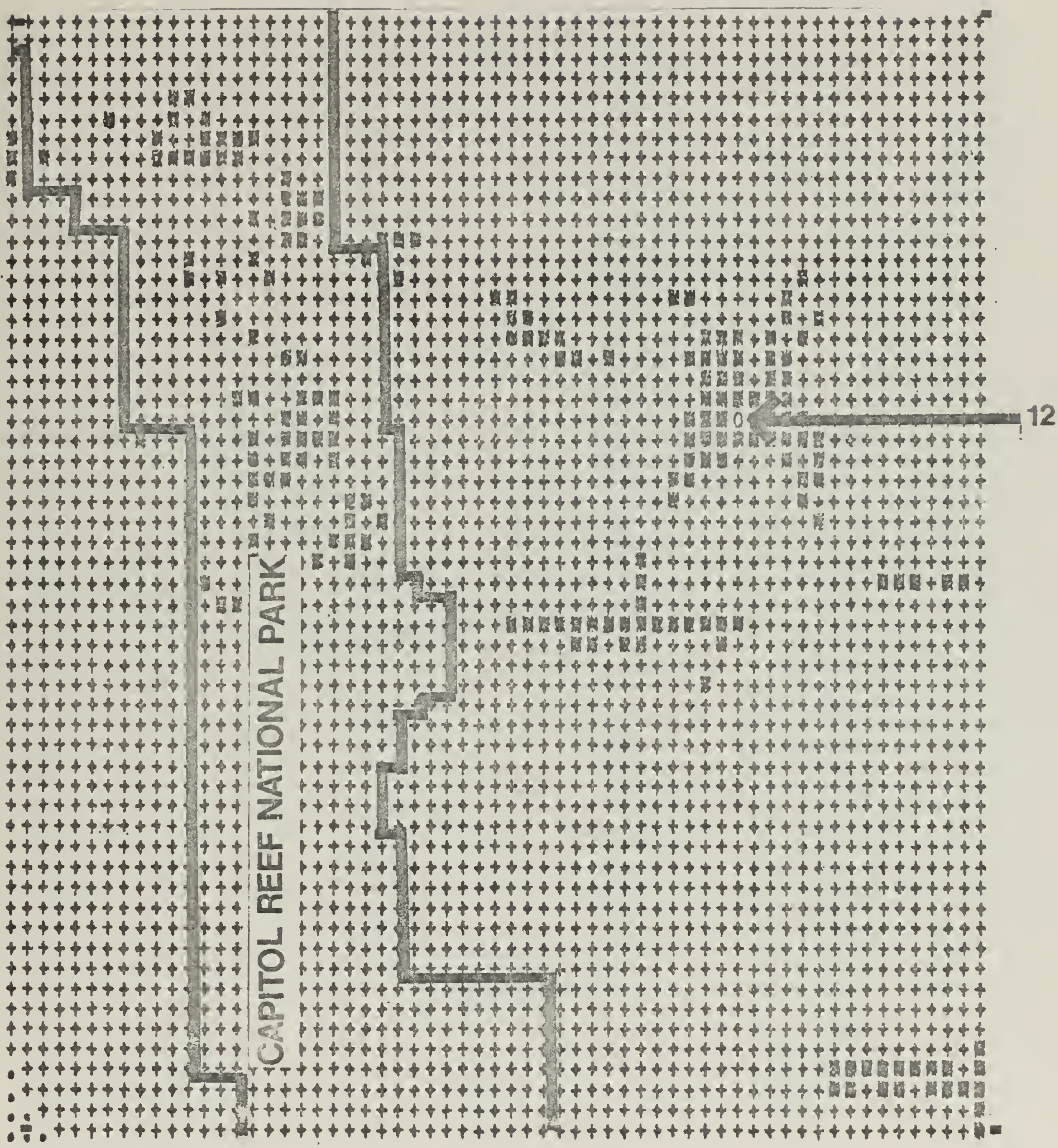


Figure 48. Observation point number 12: eye level viewing height.

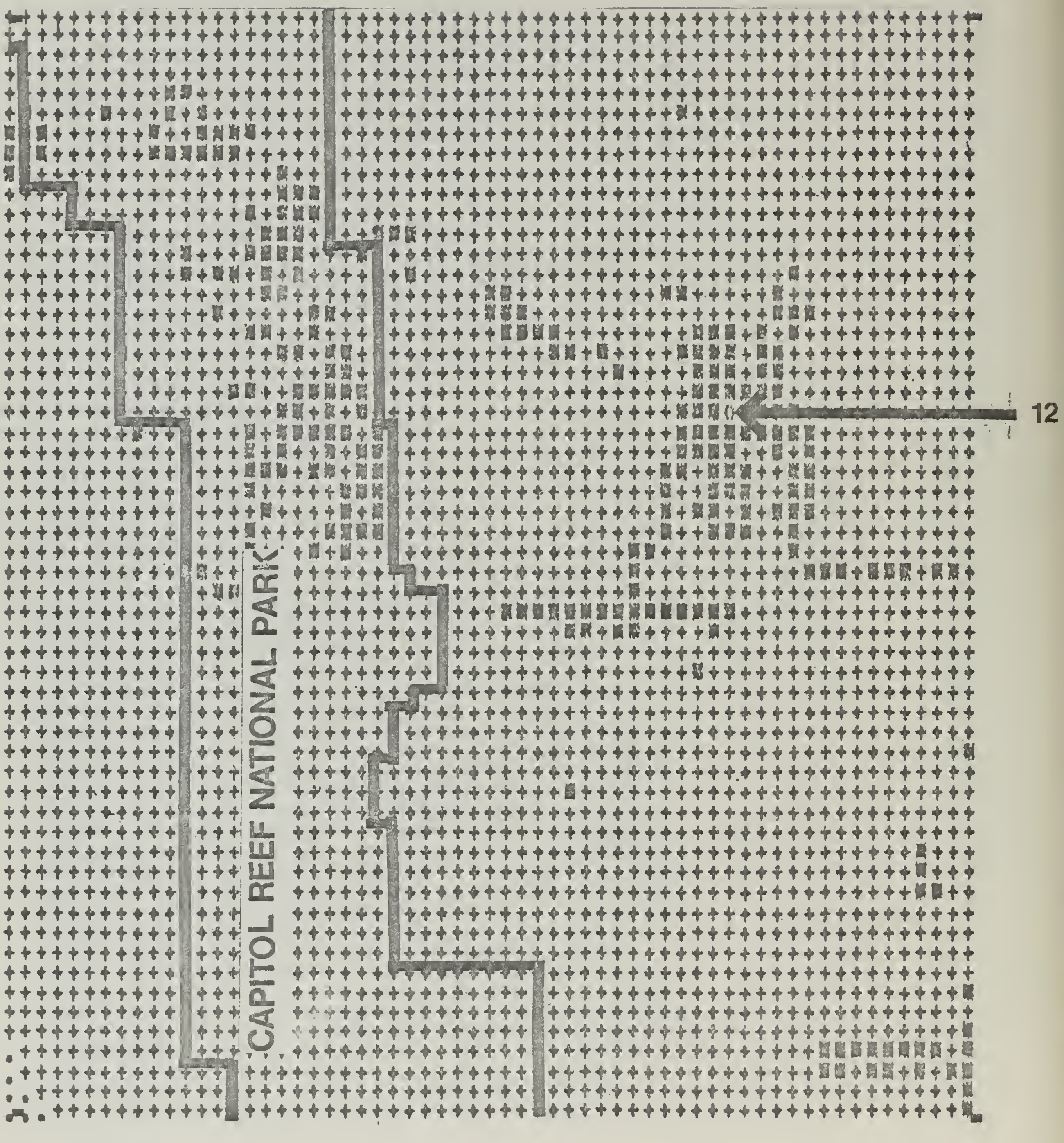


Figure 49. Observation point number 12: 50 foot viewing height.

IV. PRESENT LAND USE

A. Grazing

B. Recreation

C. Watershed

D. Wildlife

IV. PRESENT LAND USE

Present land uses in the Henry Mountains coal field area are numerous, although at a low intensity. Many uses are concurrent and are generally not in serious conflict under present management practices. Changes in land use composition are anticipated as pressures for resource use increase due to demands from urban areas, the introduction of a mobile outside population, and for energy resource development. The present and future land uses give direction to the objectives for rehabilitation of areas that may be disturbed if surface mining of the coal were to be allowed.

A. Grazing

Grazing is presently the largest single use of the lands surrounding the Henry Mountains. This use has contributed a large portion of the economic base of the region over the years. The principal base for grazing use is the extensive public lands of the region (84% in Wayne County) which provide 42,000 AUM's (1 annual unit month = feed to sustain 1 cow and calf - or equivalent - for 1 month) of forage annually which are supplemented by limited feed or pasture from private lands. Carrying capacity is extremely low for the Steele Butte allotment, which on the average is 35.1 acres per AUM (Figure 60). Approximately 34 percent of the range land is in a downward trend, with 73 percent in an unsatisfactory condition according to the Management Framework Plan (USDI, Bureau of Land Management, 1975).

A map of the Steele Butte allotment (see Figure 30) shows the vegetation types. These general types were identified in Phase I

Table 31. Range vegetation types and conditions on Steele Butte Allotment. Data are from Bureau of Land Management Allotment Management Plan (AMP) files in Hanksville and Richfield, Utah.

				Transect Averages		
Map Index #	Transect #	Vegetation Type & Dominant Species [1]	Approx. Carrying Capacity Ac/AUM	Present Soil Stability Surface Factor [2]	Range Condition Cattle	Range Condition Sheep
1	KR-10,11,12	1(9) HIJA, ATCO, JUOS *	22**	35	Good (53)	Good (3
9	KR-13,14,23	9 JUOS, GUSA *	33**	46	Fair (38)	Fair (
3	KR-3,9	9 JUOS, HIJA, ATCO *	39**	55	Fair (36)	Fair (5
4	B-1,2	9 EPNE, GUSA *	13**	34	Fair (33)	Fair (3
5	ZL-1,8,9	9 JUOS, PIED		45	Fair (16)	Fair (
6	KR-17,20 BL-4,5 BK-5 ZL-28,29,30	9 JUOS, PIED *	33**	40	Fair (31)	Poor (
7	ZL-27 BL-3	9 JUOS, PIED *	32**	43	Fair (22)	Fair (
8	ZL-21,22,23	9 JUOS, PIED		37	Good (51)	Good (
9	KR-6 ZL-14,15	9 JUOS, PIED		47	Fair (17)	Poor (
10	Z1-25 KR-1,5	9 JUOS, PIED		42	Fair (39)	Poor (
11	ZL-18,19	13 * ATCO	10**	42	Fair (57)	Fair (
12	BL-1,2 SB-1 KR-8,18, ZL-16,17,20, 24,26	13 ATCO * SAVE, HIJA	31**	44	Fair (30)	Fair (
13	ZL-6,7	13 ATCO, ATNY, JUOS		59	Fair (49)	Fair (
14	SB-2 KR-2 B-3,4	13(1) ATCO, HIJA *	25**	31	Good (70)	Good (
13	B-6 Z2-31, KR-16	13(1) ATCO, HIJA		37	Good (86)	Good (

Table 31. Range vegetation types and conditions on Steele Butte Allotment. Continued

				Transect Averages		
Map Index #	Transect #	Vegetation Type & Dominant Species[1]	Approx. Carrying Capacity Ac/AUM	Present Soil Stability Surface Factor[2]	Range Condition Cattle	Range Condition Sheep
16	BL-6 KR-21,22	13(1) ATCO, HIJA, ARLO *	20**	30	Good (63)	Good (63)
17	ZL-4,5	13 ATCO, BOGR, GUSA		42	Fair (40)	Fair (40)
18	ZL-12,13	13(9) ATCO, JUOS		54	Fair (66)	Fair (63)
19	ZL-10,11	13(9) ATCO,JUOS		52	Fair (60)	Fair (60)
20	BK-7 KR-15,19	16(1) GRSP, BOGR, JUOS		30	Good (47)	Poor (83)
21	ZL-2,3	17(4) GUSA, ARTR		40	Good (40)	Good (61)
22 Tarantula Mesa Seedlings	KR-4,7	1 AGCR (AGDE) *	26-29**	27	Good (62)	Fair (72)

* Types found within the coal lease block

** Based on old range surveys (1963-64)

1 A four letter code for plant names utilizes the first two letters of the species name. See appendix for scientific plant names and corresponding codes.

2 Soil surface stability rating

Stable	Slight	Moderate	Severe Cited
0-29	30-50	50-60	100

watershed inventory and range condition studies. Transects employing the point-step method were used by BLM personnel to evaluate range conditions for livestock grazing. The transects were established in representative areas for each type. Summary sheets on file in the BLM office in Hanksville, Utah, show map index numbers that identify transects from which data were obtained.

According to the results of the field evaluations (Table 31), in 1963-64 the number of acres required per AUM ranged from 10 in an area dominated by fourwing saltbush, to 39 in areas where juniper was the dominant species.

Grazing capacity estimated for cattle, expressed in acres per animal unit month (Ac/AUM), are shown in Figure 50 for range areas found within the coal lease lands and for the Tarantula Mesa seeding. These estimates are based on range surveys made prior to 1964 and are compiled by land sections. These values may not correlate precisely with range types shown and should be used only as first approximations.

Actual use records for the Steele Butte Allotment are partially complete. A representative year, 1973-74, shows the following:

Cows	Dates of Use	AUMs	% Actual Use
320	10/6/73 to 5/3/74	2400	100
50	10/25/73 to 5/31/74	545	61
70	3/10/74 to 5/31/74		
51	11/1/73 to 5/31/74	357	100
52	11/1/73 to 5/31/74	364	100
		3666	91%

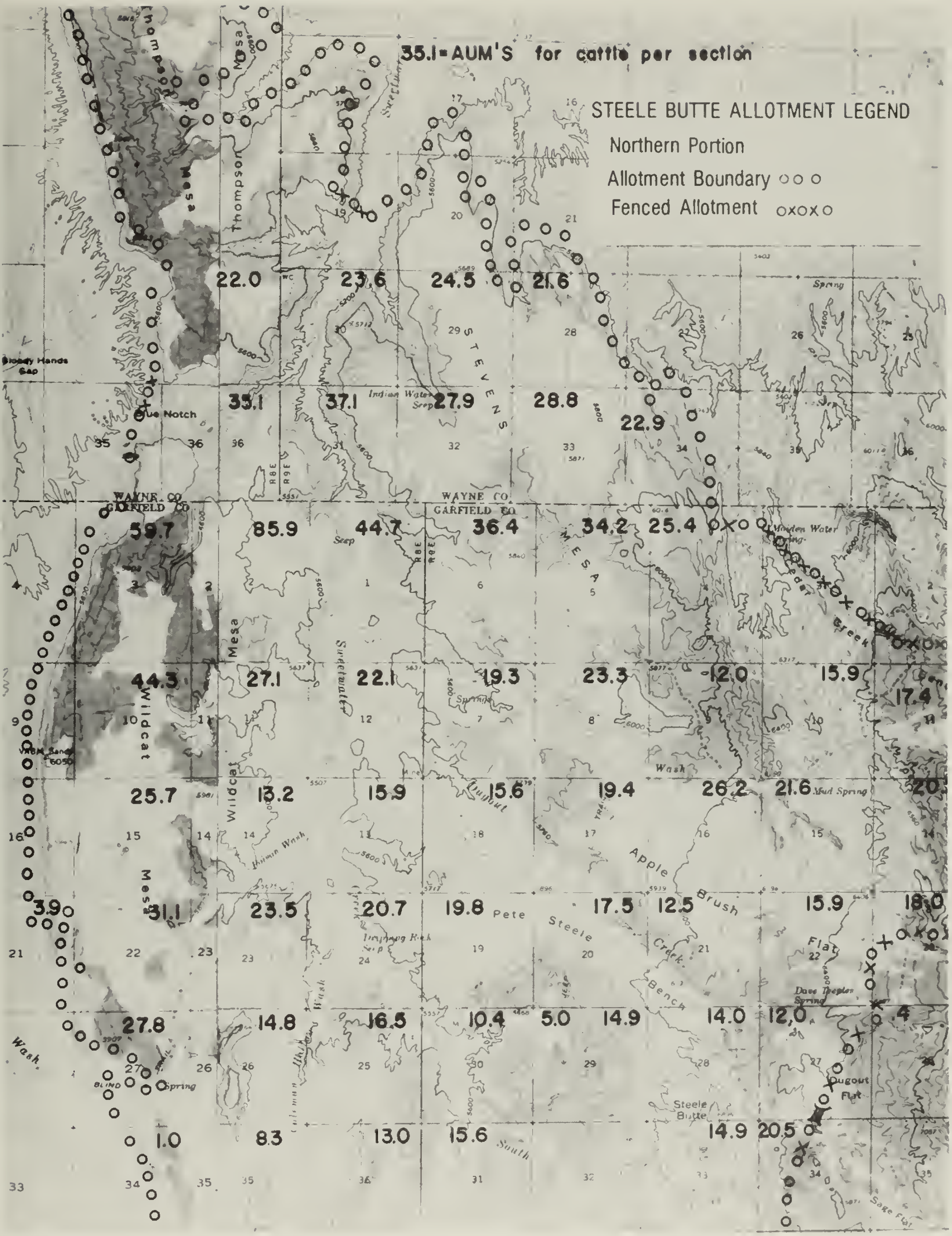


Figure 50. Steele Butte grazing allotment showing animal unit months (AUM's) of grazing capacity for each section.

Table 32. Recreational use of National Parks Service parks and campgrounds in the Henry Mountain region (Data from Agency 1976 Recreation Reports.)

BLM Site	Length of Season (Days)	Capacity No. of Persons	Total Visitor Days	Percent of Capacity (Col. 2)
Calf Creek Campground	365	115	16000	19
Cedar Mountain	180	50		
San Rafael Campground	210	50	5000	24
Hatch Point Campground	214	40	6100	6
Wind Whistle Campground	214	80	2900	8
McMillan Springs Campground	120	50	200	3
Lonesome Beaver Campground	120	65	400	2
Starr Springs Campground	240	75	8100	23
Hog Springs Campground	365	30	1000	10
NPS				
Capitol Reef Campground	365	265	35000	
Capitol Reef Picnic Area	365	100	8500	
Bullfrog Campground	365	430	*	

* Data not compatible in form with the information above.

A BLM resource analysis report of November 15, 1976, for the Steele Butte allotment shows the following:

	Acres	AUMs
Total Lands	87,418	
BLM (Public Lands)	77,741	5,040
State	7,737	
Private	1,940	

A classification of lands according to biome type shows the relative carrying capacity of various types:

Grasslands	4,440	296
Desert	10,730	536
Woodlands	62,571	4,208

The potential of the range in terms of livestock carrying-capacity of the level areas at mid-elevation such as the mesas is partially evident in the records of the Tarantula Mesa seeding, located south of the coal field study site. The pinyon-juniper type, prior to seeding, had an estimated grazing capacity of 26 to 29 ac/AUM based on range surveys. Following seeding in 1962, production studies have shown estimated grazing capacities range from as little as 2 ac/AUM during favorable years to as much as 26 ac/AUM during unfavorable years:

Tarantula Mesa Seeding

(Chained Pinyon-Juniper seeded to Crested Wheatgrass)

Dry Weight Production

	1968	1969	1970	1971
Seeding 1	720 lb/ac	1480 lb/ac	600 lb/ac	60 lb/ac
Seeding 2	620 lb/ac	1260 lb/ac		

The potential productivity of areas less favorable than Tarantula Mesa (elevation 6,400 ft) with its relatively deep sandy loam soil would not be as great. Bad lands, sandy areas, rocky outcrops and steeply sloping areas could not be considered for improvement of vegetation by conventional methods, if at all. Prudent grazing management seeks to avoid excessive stocking of these areas to prevent soil erosion. Also, because plant growth on badlands is extremely limited, the plants are more valuable for their groundcover function than for forage.

B. Recreation

One of the land uses with a present and future potential for significant increase is recreation. It is basically non-consumptive, and involves most segments of the local population, as well as natural landscapes.

The most prevalent recreation is touring and viewing, activities most easily pursued in the wide expanses and vistas available in the south central Utah region. A portion of the increased population of Wayne and Garfield counties has been attracted by economic opportunities related to recreation. Support facilities such as motels, restaurants, grocery stores, automobile service stations, marinas, and campgrounds have been developed to serve increasing numbers of people.

The Henry Mountains coal field area has considerable travel when considering its remoteness and unsurfaced roads. An average count of 100 vehicles per day going south on the Notom Road (Worthington, 1977) indicates the level of use the area presently receives.

A visitor day survey in 1976 by BLM and National Park Service provides some comparative values for recreational use of parks and campgrounds in the immediate and general area of Henry Mountains (Table 32).

Table 32. Recreational use of National Parks Service parks and campgrounds in the Henry Mountain region (Data from Agency 1976 Recreation Reports.)

BLM Site	Length of Season (Days)	Capacity No. of Persons	Total Visitor Days	Percent of Capacity (Col. 2)
Calf Creek Campground	365	115	16000	19
Cedar Mountain	180	50		
San Rafael Campground	210	50	5000	24
Hatch Point Campground	214	40	6100	6
Wind Whistle Campground	214	80	2900	8
McMillan Springs Campground	120	50	200	3
Lonesome Beaver Campground	120	65	400	2
Starr Springs Campground	240	75	8100	23
Hog Springs Campground	365	30	1000	10
NPS				
Capitol Reef Campground	365	265	35000	
Capitol Reef Picnic Area	365	100	8500	
Bullfrog Campground	365	430	*	

* Data not compatible in form with the information above.

C. Watershed

Watershed as a land use in the Henry Mountains area consists primarily of livestock drinking water, limited ranch use of irrigation for small patches of pasture for supplemental livestock feed, and for tributary flow to larger water courses. To the south, well beyond the immediate study site, surface runoff is collected in Bullfrog Creek and Hall Creek (Utah Division of Water Resources, 1975). Optimum management of watersheds will be necessary to meet priorities established by residents of Wayne and Garfield counties, which are;

1. Development of a large coal-fired power plant in Wayne county;
2. Additional development of agricultural lands; and,
3. Enhancement of recreational facilities and the tourist industry throughout the area.

The regional viewpoint and state viewpoint on these three water use priorities are essentially the same, except that there are groups who prefer little or no development but instead, favor increased recreational and aesthetic opportunities.

D. Wildlife

Habitat for wildlife in the Henry Mountains area is diverse and extensive. Water scarcity and the great annual variability in plant growth limit wildlife populations to the numbers that can survive under minimal conditions.

Deer are one of the major game species of the area. The deer herd utilizes the high slopes of the mountains and mesas in the summer. In winter, they may remain on the mesas and intermediate slopes but also utilize the lower foothills and desert where food and cover are favorable.

Recently, the Henry Mountains bison, estimated at 200, extended their winter range westward to the park boundary at the rim of Swap Mesa. These animals were introduced in the San Rafael area far to the north about two decades ago and later moved to more favorable habitat in the Henry Mountains. The Bureau of Land Management has seeded several thousand acres on Tarantula Mesa and Cave Flat to improve bison and deer habitat.

Other mammalian wildlife abundant along the western slopes, plateaus and lowlands include bobcat, fox, weasel, skunk, coyotes, and cottontail and jack rabbits. Within the Henry Mountain Planning Unit the population of mountain lions may be as many as 10. Reports from government trappers and professional hunters indicate the possibility of a winter migration of female lions across the park from Boulder Mountain to the Henry Mountains; this has never been verified by studies. Predation of livestock in this region is minimal, and control of lions is coordinated with the Utah Division of Wildlife Resources.

V. OBJECTIVES OF RECLAMATION

A. Legal Requirements

B. Management Framework Plan, BLM, Richfield District

C. Limitations and Potentials in the Objectives for Reclamation

V. OBJECTIVES OR RECLAMATION

A. Legal Requirements

The legal requirements for reclamation of lands disturbed in the development of coal resources are covered principally by the National Environmental Policy Act (NEPA) of 1969 (PL 91-190); the Surface Mining Control and Reclamation Act of 1977 (PL 95-87) and the Utah Mined Land Reclamation Act of 1975. Several federal laws also regulate specific aspects of land management such as the Endangered Species Act of 1973 (PL 93-205) and the Federal Land Policy and Management act (PL 94-529) commonly referred to as the Bureau of Land Management Organic Act.

1. Federal Laws

a. The National Environmental Policy Act (NEPA) requires that all federal agency actions shall be preceded by an environmental impact study (Public Law 91-190 1969). An environmental analysis shall, among other factors, include an assessment of the impact of the proposed action on the environment, alternatives to the action, and identification of appropriate measures to mitigate the impacts of the proposed action. Therefore, rehabilitation planning and implementation are mandated by NEPA.

b. The Surface Mining Control and Reclamation Act of 1977 regulates the issuance of permits by state and federal programs under section 515. Provisions of section 515 specify the performance standards necessary to assure environmental protection. Some of the performance standards that would be applicable to the Henry Mountains Coal Field are:

(1) Restore land to a condition capable of supporting

the uses which it was capable of supporting prior to mining.

(2) Restore lands to their original contour unless other environmental values can be achieved by other contours.

(3) Stabilize and protect all surface areas to prevent erosion and water or air pollution.

(4) Replace topsoil or utilize other strata if it is more suitable for vegetation requirements.

(5) Create, where authorized in the mining and reclamation plan, impoundments of water as a part of reclamation activities.

(6) Minimize the disturbance to prevailing hydrologic balance.

(7) Stabilize waste piles and assure their contours are compatible with surroundings.

(8) Treat or bury all debris and toxic materials.

(9) Control or prevent erosion resulting from construction or access roads.

(10) Establish on regraded and affected lands a diverse effective permanent vegetative cover similar in ecological aspects to the native flora.

(11) Assume responsibility for successful revegetation for a period of five years after the last year of planting and other revegetation work.

Variance provisions, specifications and mitigating circumstances are described in addition to the performance standards.

Implementation of this federal law is effected through a permit that would be issued at the state and local level. Each permit application shall be accompanied by a reclamation plan that meets provision of Public Law 95-87.

c. Other federal regulations may apply. In terms of planning for multiple use and disposition of lands as set forth in Title II section 202 of the Federal Land Policy and Management Act (PL 94-579). The act requires, among other considerations, that the development of land management plans shall:

(1) Give priority to the designation and protection of areas of critical environmental concern.

(2) Consider present and potential uses.

(3) Weigh long-term benefits against short-term benefits of land use.

(4) Consider relative scarcity of values involved and the availability of alternatives.

(5) Provide for compliance with applicable pollution control laws.

The Endangered Species Act of 1973 (PL 93-205) prohibits development of areas that would take a rare and endangered animal or plant species or damage areas of critical habitat. Mitigation of impacts of development may be considered if alternate habitats can be developed. In the case of the Henry Mountains coal field, no threatened nor endangered plant species have been recorded in the immediate area (Welch, 1977). A number of threatened or endangered species were recorded in the plateaus to the west, however. There may be some concerns expressed for the bison herd which may seasonally occupy portions of the plateaus west of the Henry Mountains at elevations lower than the high mountain slopes. The most frequently occupied mesas are Tarantula Mesa, Cave Flat and Swap Mesa which are south of Wildcat Mesa.

2. State Laws

a. General

A perspective of various state requirements for reclamation of surface mined lands was summarized by Imhoff, et. al. (1976). Generally the provisions required by Utah are similar to other states, although the actual implementation of such provisions may be more or less stringent than described depending on individual interpretation and site conditions. The Utah Mined Land Reclamation Act of 1975 states that the objective of revegetation should be, "to stabilize the land as quickly as possible after it has been disturbed in order to achieve permanent and protective vegetative cover. Non-noxious native plants that will give a quick permanent protective cover and enrich the soil shall be given priority."

b. Utah law

According to Utah State law, before any operation shall commence mining, the operator shall file a reclamation plan with the Utah Division of Oil, Gas, and Mining which describes:

(1) A statement of prior and current uses.

(2) Possible uses for the land following termination of mining.

(3) The manner in which the overburden, topsoil, tailings, waste and rejected materials would be deposited.

(4) The manner in which plant supporting materials would be conserved and restored.

(5) The manner and extent to which grading, backfilling, and compaction will be accomplished.

(6) How a planting program on an alternate practical procedure would be done to minimize or control erosion and siltation.

(7) A timetable for accomplishment.

3. Local laws

Garfield county has no regulations or ordinances pertaining to land use or reclamation. A subdivision ordinance exists, but this only applies to applications for housing developments.

B. Management Framework Plan, BLM, Richfield District

Within the management framework plan developed by district resource technicians (BLM, 1975) requirements for land rehabilitation are based on several criteria, the most important of which is the need to manage for multiple use. Specific objectives include management to sustain existing uses such as grazing, wildlife habitat, watersheds and recreation; to maintain environmental quality by avoiding practices that would cause pollution or require that they be ameliorated by appropriate measures, to manage the land for the optimum benefit to the citizens of the county and to seek a balance in the management of land in such a manner as to meet national needs.

C. Limitations and Potentials in the Objectives for Reclamation

1. Limitations

Some of the most obvious limitations for reclamation in the area of the Henry Mountains coal field are associated with the dry climate of the region. Meager precipitation (estimated annual average 8 to 9 inches) which has a large variation from year to year, is perhaps the greatest limitation to the establishment of a replacement plant cover. The effects of limited rain are further reflected in the minimal development of soil to sustain plant growth.

Another limitation is the yearly migration of the bison herd from the slopes of the Henry Mountains to high plateaus such as Tarantula Mesa. Wildlife species such as deer or mountain lion with a wide range of distribution or extensive migration patterns may be seen as being limited unless appropriate mitigation measures were taken.

Insufficient supply of water to sustain rehabilitation and seeding practices may be a limitation to certain kinds of practices for establishment of a plant cover and other resource uses. Alternative methods may have to be used or developed specifically for the area.

2. Potentials

The potential for revegetation will be dealt with more fully in a subsequent section. However, as a general rule the harsh climate of the area severely limits the potential for revegetation although not other land reclamation practices.

It is evident from a look at existing vegetation that plant establishment and growth occurs under natural conditions even though favorable years for establishment may be infrequent. The potential for establishing a vegetation cover exists if problems of limited and infertile soil, scarce rainfall, high summer temperatures, and animal utilization during early stages can be alleviated. Recommended practices are intended to deal with some alternative establishment strategies.

The potential for avoiding disturbance of bison and other wildlife species and loss of habitat also exists depending upon subsequent decisions for mining and enhancement of habitat or changes in management practices.

VI. RECOMMENDATIONS FOR REHABILITATION

A. Potential for Rehabilitation

B. Recommendations for Rehabilitation

VI. RECOMMENDATIONS FOR RECLAMATION

A. Potential for Rehabilitation

1. An overview

On the basis of data and descriptions of the climate, soils, and present land uses of the study area and the Henry Mountain coal field, it is clear that vegetative rehabilitation can only be accomplished with the greatest of care and use of appropriate methods. Although a common dictum in rangeland improvement is to seed only in areas where the average annual precipitation is eleven inches or more, some success can be expected in the 9 to 10 inch zone under favorable conditions (Valentine, 1971). Rangeland seedings have been limited to low-cost projects involving minimal land treatments and cultural practices because of the relatively low-value returns that can be obtained. In contrast, surface-mined areas may justify more elaborate treatments and qualify for expensive practices because of the high-value energy resource involved (Persse, et. al., 1977).

The Study Committee on the Potential for Rehabilitating Lands Surface Mined for Coal in the Western United States (1974) observed that not all western coal lands may be amenable to rehabilitation because of harsh climatic conditions, limited soil development, and a lack of suitable methodology. The degree to which these apparent limitations can be mitigated will determine the success that may be possible in rehabilitation. An encouraging fact is that under natural conditions plant establishment has occurred to provide the existing vegetal cover. Within the species represented in the various plant communities, plants occur that are particularly adapted to drought, salinity, unfavorable soil physical conditions and utilization by animals. From an examination of these species and the local site conditions the potential for rehabilitation appears to be positive, although difficult.

2. Implications

The increasing need of the nation and the region for energy sources places a high priority on the responsible development of high quality coal that is easily mined. Jobs and improved economic welfare of local people also appear to have a high priority, but at the same time the generally increasing economic opportunities generated by recreation and tourism may be of equal or greater long-term benefit than the coal-related jobs. Since land rehabilitation is necessary for coal development to occur, some water as well as scenic values presently used or planned to support recreation may have to be committed to achieving the difficult potential for rehabilitation.

Any method(s) recommended must include a keen awareness that a number of local factors be fully considered. The limited annual precipitation of 8-9 inches extrapolated for Wildcat Mesa is undoubtedly the most critical factor. This precipitation is less effective than would generally be apparent because a large proportion occurs in the summer months when evapotranspiration losses are the greatest. Revegetation methods must include some type of irrigation or unique method to maximize the timing and amounts of existing rainfall in relation to the growing season. Even so, the great variation in precipitation from year to year may preclude revegetation success in dry years, such as 1977. Therefore, achievement of desired revegetation under natural conditions may require several years - 10 or more.

In general the soils are shallow and sandy except where Masuk

Shale is the parent material. Here the soils are heavy and sticky when wet, are high in salinity and crack when dry. Special techniques will be required to handle soils in some areas, and the common requirement to save and store topsoil for subsequent use as a top dressing may not always be feasible or worthwhile.

Existing land uses, particularly wildlife habitat and livestock grazing, would require adjustments. It would be desirable to provide to offset those lost by surface disturbance. More serious is the problem of natural migration of wildlife through the area or adjacent areas. Deer and bison may be most affected although other large animals such as cougar may also be impacted.

3. Criteria of Importance in Developing Recommendations for Rehabilitation

The most important general criterion is that methods used must provide a reasonable chance for success within economic limits for the western U. S. (Persse, et. al., 1977). Efforts should be expended to make maximum use of existing resources such as plants, soil, and precipitation in a fashion that will sustain a self-regenerating system (McKell, 1976). Major criteria for consideration include:

a. Plant species must be adapted to local climate, soil and animal use.

b. Plant establishment methods must either be appropriate to local precipitation patterns and/or receive irrigation.

c. Surface shaping should be site specific and suitable for the hydrology of the area.

d. Topsoil requirements should be consistent with quality and availability of topsoil on areas to be mined.

- e. Post-establishment management should protect plants from livestock and wildlife.
- f. Post-mining land use should be consistent with regional social patterns and environmental limits.
- g. Commitment of long term expensive management practices should be minimal.
- h. An extended period of rehabilitation should be expected in this arid environment.
- i. Further research on plant establishment under arid conditions must be undertaken to provide specific information and techniques suitable to this arid region.

B. Recommendations for Rehabilitation

Based on available information and investigations conducted during this EMRIA study, a number of recommendations can be made. Some of these recommendations will require further refinement before they are valid for local conditions. The following order of discussion does not imply any priority for consideration.

1. Determine the most suitable mix of post-mining land uses. Given the scenic and recreational potential of the general region, wildlife habitat should be the principal land use, but not subordinate to watershed or scenic value. Livestock grazing could be permitted after a suitable period of ecosystem stabilization and to the degree compatible with wildlife use. The present economic need for grazing AUM's in the local communities would be offset by increased economic activity generated by mining and recreation.

2. a. Mining activities should be conducted so as to permit the identification of geologic materials high in toxic properties so that

such materials can be buried deeply. Otherwise, a general mixing of geologic overburden would appear to be permissible.

The greenhouse bioassay indicated that toxic properties of certain overburden samples were associated with pH lower than 7, EC higher than 4.0 and boron content in excess of 1.0 PPM. Results did not indicate that any lithotype was more suitable chemically than another. The field establishment study and observations of native plant communities of the area suggest that sandy materials will be better than clay materials as plant growth media. Mixing of overburden strata would probably be an improvement. Further testing of the materials would be desirable during the mining operation.

b. Mining activities should be kept confined to localized areas to avoid disturbance to wildlife. East-west mining starting at the north end of Wildcat Mesa would pose the least barrier to the migration of big-game animals going from the desert floor up to the mountains.

c. Road construction should be planned to minimize problems of dust, wildlife migration, water pollution and visibility from Capitol Reef National Park and the upper reaches of the Henry Mountains. Appropriate dust control measures such as application of gravel or water, if it is available, is recommended. Early destruction and planting of collector roads no longer needed for access is also recommended as soon as units of land are ready for rehabilitation.

d. Back filling and rough grading should not be delayed beyond the actual time needed for mining activity. Minor surface roughness during any interim period is encouraged to serve as a deterrent to dust and sand movement. The surface at this time should be such that any precipitation received should percolate into the soil, thus beginning normal processes of leaching, weathering and, recharge of soil water content.

e. Visibility should be considered a sensitive problem. Certain high places in Capitol Reef National Park and on the Henry Mountains permit a view of the proposed mining area.

3. Soil and Overburden Placement

a. If surface mining is conducted in areas where FaB, HaB or HaC soils (see USDA, SCS 1977) occur, these soils should be used as topdressing. The soils designated as GaG or GaD should be avoided. All soils are high in magnesium and some in exchangeable sodium. Although Fa and Ha soils are high in magnesium they are not strongly calcareous. Fertility trials in the field should be established to further investigate this relationship. Any soils or overburden material meeting the following criteria sould be acceptable as topdressing or as a general mix of the geologic materials:

(1) Water soluble boron content less than 1.0 ppm
(2) EC of saturated extract less than 4.0 mmho/cm
(3) pH of saturated paste between 7.0 and 8.5
(4) Gravel (diameter > 2.0 mm) and stone percentage less than 15
(5) Avoid coaly material in top dressing

It is recommended that all materials used for topdressing be tested to assure that the above criteria are met. It is desirable that topdressing be 24 inches deep, with 12 inches being a minimum.

b. The geologic material directly below the topdressing, to a total depth for topdressing and "subsoil" of 4 feet, should meet the same criteria for boron, Ec, pH and clay content as the topdressing, but gravel and stone content may increase to 30 percent. Materials with toxic properties should be buried well below 4 feet deep.

c. The possibility and feasibility of creating a suitable soil profile for plant growth should be considered and researched. An optimal reconstructed soil profile should provide an adequate depth and water holding capacity for various plant species to grow under arid conditions. Infiltration rate and water-holding capacity of the soil are critical factors in the survival and growth of vegetation. For example, deep cracks in the bedrock below a shallow topsoil provide a soil moisture reservoir for shrubs and trees. In other sites, a restrictive clay layer may serve to retain soil moisture in the root zone. The volume of soil above the restrictive layer should be sufficient to sustain a productive vegetation cover. In the replacement of overburden removed by surface mining a layer of fine-textured soil overlain by a strata of sandy soil may provide a profile configuation that would sustain plant growth under arid conditions. In such a case, precipitation could rapidly infiltrate the sandy textured soil material but be held in the fine textured material with a high water-holding capacity. A number of profile configurations should be considered and studied to determine the most favorable in relation to the proposed uses after mining and the requirements of plant species selected for use in the revegetation plan.

d. Surface mulching is recommended as a general practice for aiding plant establishment and growth and also for other benefits it may provide such a surface stabilization, increased water holding capacity and decreased surface heat exchange. Although a limited amount of mulch may be available from shredding the juniper trees in the area it is not considered practical and would need to be augmented by use of straw or similar type materials. Recommended rates would have to be determined according to local conditions. However, a preliminary recommendation is 1,000 lbs/acre as a minimum, based on reports in Reclamation and Use of Disturbed Land in the Southwest (Thames, 1977).

Surface-film-type mulches for soil particle stabilization may be applied after seeding or transplanting. Cost considerations and rates would have to be determined for such materials as polyvinyl acetates, styrene butadiene latex, and asphalt emulsions, with and without added organic mulch materials.

4. Shaping of Spoils

a. The original contours of the site should be maintained as much as possible. In general this consists of nearly flat to gently sloping mesas with steep escarpments. The escarpments are usually very rocky with sparse or almost no vegetation. In the rehabilitation process the escarpments overlooking drainage ways, such as Sweetwater Creek or Poison Wash, might be partially restored by replacing large boulders. Fine earth particles between the boulders could support some vegetation, although the major concern in rehabilitating escarpment areas will probably be erosion control, rather than production of plant biomass. Restoring the natural contours would be aesthetically desirable, and the gentle slopes of the mesa tops would facilitate erosion control and plant establishment.

b. Water harvesting possibilities should not be overlooked in the plans for shaping of spoils following mining. Water harvesting for sustaining plant growth in arid regions is an ancient practice (Evenari et. al., 1971) but it has not received adequate modern attention as an alternative strategy or supplement to irrigation. Shaping of the land surface to create gentle northeast facing slopes would not only have a more favorable heat balance but would also be suitable to provide runoff to planting sites at the bottom of short slopes for plant establishment and growth. More steeply sloping southwest exposures may be left untouched to provide physical diversity or may be surface-treated (Aldon and Springfield, 1975) to provide runoff and particle stability.

c. Micro-habitats for plant establishment should be worked into the plan for spoils shaping. As Harper (1965) has pointed out, "safe sites" may be needed for plants to become established in harsh environments. Uneven surface, slopes, mulch or shaded spots may enhance plant establishment. Dollhopf et. al., (1977) in Montana describe various surface configuration techniques useful in creating micro-habitats and also minimizing surface runoff. One of the most successful techniques is a surface gouging to increase water infiltration and a favorable site for plant establishment.

d. Compaction of areas to be planted should be avoided. This does not preclude firming of the seed bed or packing of loose soil. Areas that inadvertently, or by necessity, become compacted should be loosened by chiseling, discing, or furrowing.

5. Vegetation Establishment

Establishment of vegetation in the general area of the study may be considered to have only a marginal chance of success unless appropriate measures are taken to mitigate the deficiences of limited precipitation and low productivity topsoil. Appropriate practices to increase the efficiency of moisture use or to augment the normal precipitation by irrigation must be employed.

The soil should be left fallow over winter to accumulate moisture before early spring planting. If insufficient precipitation is received, planting may have to be delayed or plans modified. A period of fallow is not needed if the land is irrigated.

Although success in direct seeding has been obtained on Tarantula Mesa and the slopes of the Henry Mountains after pinyon-juniper control by chaining, the environmental conditions at Wildcat Mesa are more arid and the soil conditions would be less favorable. Possibilities for dry periods are frequent and the extremely dry conditions of 1976-77 serve as a caution to those given the responsibility for vegetation establishment. Rehabilitation and vegetation establishment under the harsh condition of the site will require considerable time. A minimum of 10 years should be allowed for beneficial results to occur.

a. Direct seeding should not be attempted without irrigation in this arid location. Irrigation may need to be applied before seeding to allow a build up of soil moisture. Irrigation should then be continued on a regular basis after seedling emergence throughout the first growing season. The soil surface should have been previously mulched to reduce evaporation of soil moisture and to reduce possible surface crusting after seeding.

b. Transplanting of bare-root stock or, preferably, container-grown plants native to the area can be successful in average or above average precipitation years without irrigation (Van Epps and McKell, 1976). In drought years, such as in 1977, supplemental irrigation will be required to insure plant survival, and even in good moisture years supplemental irrigation can increase survival and growth of transplants. Container transplants can be started from rooted stem cuttings or rhizome sections or wildlings as well as seeds, thus expanding the number of species that can be planted. Field survival and growth of transplants increases with the size of container and size of container-grown plants (Barker, 1978). Transplanting is best accomplished in the spring to take full advantage of the growing season. The soil should be moist at the time of planting, either from natural accumulation or irrigation. Further research is needed to reduce the cost and increase the efficiency of producing and planting transplants.

A method that can be used for some species, such as the rhizomatous galleta grass, is to transplant whole plants or vegetative parts along with the soil used as topdressing.

c. Plant Selection

Table 33 shows recommended plant species for rehabilitation of areas of the Henry Mountains coal field averaging 8 to 10 inches of annual precipitation. Ratings of relative salt tolerance, palatability to livestock and soil surface stabilizing ability and methods of propagating the species are also shown. Planting of greasewood and rubber rabbitbrush should be limited to areas near water courses. Utah juniper will perform best on rocky slopes where water running off the rocks accumulates. All of the species listed are native to eastern Utah except Russian wildrye and prostrate kochia.

Seeds, vegetative propagules (e.g. rhizomes, stem cuttings) and transplants should come from the vicinity of the mine sites or from areas with similar climate and soils. Species not native to the site or plant materials from different climatic regimes should be tested in field nurseries on the site before large scale plantings are attempted.

Table 33. Suitability of various plant species for rehabilitation of the Henry Mountains coal field.

Botanical Name	Common Name	[1]Salt Tolerance	[1]Palatability to Livestock	[2]Method of Propagation	Soil Surface Stabilization
Shrub or tree					
Atriplex canescens	fourwing saltbush	3	3	S,C	1
Atriplex confertifolia	shadscale	3	2	C	1
Atriplex corrugata	mat saltbush	3	1	C	3
Atriplex cuneata	cuneata saltbush	3	3	C	3
Ceratoides lanata	winterfat	2	3	S	1
Chrysothamnus nauseosus	rubber rabbitbrush	1	1	S	1
Chrysothanmus viscidiflorus	yellowbrush	1	1	S	1
Ephedra spp.	joint fir	1	2	S	2
Grayia spinosa	spiny hopsage	2	2	S,C	1
Juniperus osteosperma	Utah juniper	1	1	?	1
[3]*Kochia prostrata*	prostrate kochia	2	3	S,C	1
Sarcobatus vermiculatus	greasewood	3	1	S	1
Grass					
Bouteloua gracilis	blue grama	1	3	S	2
[3]*Elymus junceus*	Russian wildrye	1	3	S	2
Hilaria jamesii	galleta	1	3	R	3
Oryzopsis hymenoides	Indian ricegrass	1	3	S	2
Sporobolus aeroides	alkali sacaton	2	3	S	2
Sporobolus cryptandrus	sand dropseed	1	3	S	2
Forb					
Hedysarum boreale var. *utahensis*	Utah sweetvetch	1	3	S	1
Sphaeralcea spp.	globemallow	1	1	S	1

1. High or good = 3. Moderate or fair = 2. Low or poor = 1.
2. Seed = S. Stemcutting = C. Rhizome = R.
3. Non-native

Seed mixtures of adapted species (see Table 33) and ecotypes should be planted in the Spring at depths of 1/4 to 1/2 inch, depending on seed size (shallow for small-seeded grasses, deeper for larger seeded shrubs). Proper seed placement and depth is best accomplished with a rangeland drill. Broadcasting of seed over a previously roughened (e.g. by pitting) spoil surface and allowing the sloughing of soil to cover the seeds is not generally recommended. The unavailability of sufficient quantities of seed or poor seed germination characteristics will exclude many valuable species. Native seeds may be obtained from a number of commercial collectors (Crofts and McKell 1977).

d. Density of plantings should be sufficient to ultimately provide a vegetation cover similar to that existing prior to mining. According to range surveys conducted by BLM, the average vegetation cover, composed of all species, is generally 20 percent. Not all of this cover is composed of perennial or desired species. A recommended guideline is to seed or plant key perennial species such as juniper, fourwing saltbush, shadscale, ephedra, mat saltbush, Indian ricegrass and blue grama grass only in sufficient density to set the direction of plant succession and increase ecological stability. Other plant species especially annuals, may invade or occupy the site because of their presence in topsoil or by being transported in by wind or animals. However, their presence may not be a detriment as long as the key species have been well established. Transitory annuals may well improve the site by adding organic matter and feed for small rodents. Weed control measures may be needed to prevent undue competition with the key species during establishment.

e. Aesthetic considerations

Because of the high regional priority for scenic quality in relation to recreational use, all operations, especially revegetation, should be planned to avoid any significant long term deterioration of scenic values. The following recommendations should be considered.

(1) Select species for planting that are native or compatible in their appearance with the vegetation of adjacent areas.

(2) Seek natural appearing lines and contours in planning revegetation -- avoid straight lines, sharp boundaries and stark color and shape contrasts in planted and adjacent areas.

(3) Plan a blend of natural contrasts in color, size and shape in the vertical and horizontal appearance of the plant community that would occur from planting or seeding.

(4) Seek a species composition mix that will be similar in periods of growth activity to adjacent areas.

(5) Begin vegetation establishment as soon after mining as possible, keeping in mind the need to accumulate moisture in the soil prior to planting. In areas subject to high wind velocity special precautions such as a rock surface mulch or roughness may be necessary.

For the most part, adherence to the above criteria will be possible through the choice of native species.

6. Water Availability and Use

a. Possible Sources of Water

(1) Surface Waters and Springs. Goode and Olson (1977), in their reconnaissance appraisal of the water resources of the Henry Mountains coal field have concluded the following:

> Observations during the 1975 and 1976 field seasons after winters of normal precipitation and during the 1977 field season, after a dry winter, confirm that springs and the mountain streams fed by them cannot be depended upon each year as water supplies...In years of normal or excessive precipitation water from springs by pipeline in amounts of 200 to 400 acre-feet per year [may be available]... Water imported from Oak Creek and/or Pleasant Creek might supply 2000 to 3000 acre feet per year if water rights can be purchased from present owners... likely these sources of water would be no more dependable than the springs in the Henry Mountains.

Discharge estimates and measurements on Sweetwater Creek, immediately adjacent Pete Steele Bench, were made by Goode and Olson (1977, Appendix B, Table 7) and estimates or measurements of flow of 52 springs were also made within the Sweetwater drainage (Goode and Olson, Appendix A, pages A-2 to A-8. The various measurements support the above conclusions. For example, Dugout Creek, a tributary to Sweetwater Creek, yielded 600 to 750 gpm in its upper reaches in 1975 and 1976 but was down to an estimated 5 gpm in 1977.

(2) Water Harvesting. Water harvesting is the process of collecting and storing precipitation from land that has been treated to increase the runoff of rainfall and snowmelt. At the present time water harvesting is generally not accepted as an alternative method of providing water for agricultural or culinary purposes although over 3000 water harvesting systems have been installed around the world (Cooley, Dedrick and Frasier, 1975). Some method of water harvesting

should be attempted. Collection areas should be large enough to provide the amount of water needed but care must be exercised to control sedimentation. Variables to consider include annual precipitation, permeability of the collection area, and expected evaporation from the collection area and storage facility. In a 10-in precipitation isohyet, 1-yd^2 should yield 56 gallons of water, if there are no losses.

(3) <u>Groundwater</u>. In the Colorado Plateau province, with exception of the deep Grand Canyon in northern Arizona and the high plateaus in Central Utah, the succession of strata is almost entirely sandstones and shales, with few or no carbonate units. The sandstones are the aquifers.

Beneath a possible well site along Sweetwater Creek in the study area the downward succession of stratigraphic units would be:

Emery Sandstone Tongue, lower member
Blue Gate Shale
Ferron Sandstone Tongue
Thunuk Shale
Dakota Sandstone
Shale Member of Morrison Formation
Sandstone Member of Morrison Formation
Summerville Formation
Entrada Sandstone
Carmel Formation
Navajo Sandstone
Kayenta Formation
Wingate Sandstone

Of these seven sandstones the Navajo is generally recognized as the best potential aquifer because of its thickness, better sorting and hence highest porosity. This conclusion is again supported by Goode and Olson (1977) in their assessment of the water resources of the Henry Mountains coal field.

The Lower Emery and Ferron sandstones outcrop about the study area in the faces of escarpments where recharge opportunities are small. The Dakota and Morrison sandstones are relatively thin with limited recharge opportunities in the area being considered. The Entrada Sandstone in this general area is in its so-called red earthy facies, with a large proportion of fines, and hence low porosity. Water furnished by it tends to be of low quality (Goode and Olson, 1977).

In their final appraisal of the water resources of the area Goode and Olson report that the Navajo Sandstone beneath the study area is probably saturated with water under artesian pressure.

Considering a well to be located along Sweetwater Creek or Poison Wash in the study area, at approximately 5,500 feet, the top of the Navajo Sandstone beneath would be at an elevation of 1,000 feet, and the well 500 feet into the top of the Navajo would be 5,000 feet deep. Artesian pressure would cause the water to rise thousands of feet toward the surface. If the Navajo were not fractured, the well's coefficient of storage and its transmissivity would be small, but still might yield 60-100 gallons per minute.

Recharge areas of significance for the Navajo near the study area are to the west and northwest, where perennial streams drain from the high plateaus, Boulder and Thousand Lake Mountains, across the Navajo outcrop in Capitol Reef National Park. Presumably the Navajo Basin is full to these crossings of Oak Creek, Pleasant Creek and the

Fremont River, since they have had ages to fill the aquifer to its capacity. If much water were pumped from the Navajo in the study area, additional recharge would finally be induced from these streams. The time of such induction would depend upon the transmissivity of the aquifer, and the quantity of water pumped. For the several hundred gallons per minute for rehabilitation and operation of the mine, the time might be very long indeed.

What quality of water to expect from a well along Sweetwater Creek is a question, since the quality of water found in the Navajo varies from a few hundreds parts per million to a few thousands parts per million to tens of thousands of parts per million (Goode and Olson, 1977; Feltis, 1966).

Water drawn from the Navajo Sandstone falls into two categories: dissolved solids in the range of 933 to 4200, and dissolved solids in the range of 188 to 442. Wells north of the Fremont River are in the former category; five wells scattered among five townships, from 29 to 36 south, on both sides of the Henry Mountains, are in the latter category. Near outcrop areas where recharge is rapid the quality may be good; at greater depths where the water has been confined for ages, it may be very poor. The study area appears to present an intermediate situation. The question of the quantity and quality of water that may be obtained in the proposed mining area should be settled by a test well, as soon as practicable.

b. Irrigation Requirements. Jeppson et al. (1968) show average annual potential evapotranspiration for the study site to be between 21 and 27 inches per year. When this potential is compared with an average annual precipitation of 6 to 8 inches, it is obvious that a significant deficit exists. Most of the potential evapotranspiration occurs during the growing months of March through October. The observed deficit of perhaps 20 inches is the irrigation requirement for a grain crop in the Hanksville area (Dick Griffin, personal communication).

Irrigation guidelines for rehabilitation of spoil piles will vary depending on availability of water, quality of water, drought stress, plant species, and method of planting. To completely overcome drought stress of native plants with growth characteristics similar to a grain crop, an application rate of about 1.7 acre-feet per acre per year would be required. This is in addition to expected rainfall amounts. However, since young native plants are often capable of surviving at least a moderate drought stress, then perhaps much less irrigation water would be required. Assuming that native plants might be established with as little as 2 quarts of supplemental irrigation per plant, or 2 quarts per yd^2, then required irrigation would amount to only .007 acre feet per acre per year. This calculation assumes direct application to the base of the plant where the water is readily available to the root system. Otherwise such a small addition of water would simply be lost to evaporation.

Actual irrigation requirements will probably range somewhere between 1.7 and .007 acre feet per acre per year depending on rehabilitation objectives and other factors.

A well yielding 60 gallons per minute continuously throughout the year would provide 100 acre feet of water. With storage, this could provide application of water to 100 acres at intervals as desired to a yearly total of 1 foot. More rapid application directly from a well without storage, would of course require a larger capacity well.

7. Fertilization of Soils and Overburden

Most soils and overburden samples tested were extremely low in available nitrogen (N) and phosphorous (P). Some of the overburden samples were low in available potassium (K) as well. Annual fertilization for the first 2-3 years is recommended but only in low quantities (30 lb N and 30 lb P per acre) because plants are not able to respond to high soil fertility under arid conditions. It is also believed that the native plant species have low soil fertility requirements. However, if irrigation is practiced higher levels of applied fertilizer will be required. Potassium fertilizer should be needed only if available ($NaHCO_3$ extractable) K levels are below 80-100 ppm.

Further research is needed to determine the actual soil nutrient requirements (minimal and optimal) of native arid-land plants under various degrees of aridity and supplemental irrigation. The possibility of increasing the ability of native plant species roots to absorb phosphorous, other soil nutrients and water by innoculation of the soil or spoil with the appropriate mycorrhiza-forming fungi should also be researched to ultimately reduce the need for addition of supplemental fertilizer and water might be reduced.

8. Recommended Practices to Ameliorate Impacts to Wildlife

There are only a limited number of things which can be done as mitigation assistance to wildlife should coal development occur. Possible suggestions for this are listed below. The Utah Division of Wildlife Resources may have other alternatives that should be considered. Because the (sensitive) range of the bison may be impacted, several approaches or a combination of approaches could be taken. (a) Restrict (road) access in the area of the development to reduce miscellaneous impacts from increased recreation use. (b) Provide funds for development of improved buffalo ranges in other areas on the mountain.

9. Management Activities to Reduce Pollution of Air and Water

The potential mining site is in an area subject to strong westerly winds that can be exceptionally strong under certain conditions. There is evidence of blowing sand and dune formation at the south end of Wildcat Mesa. Violent short-duration summer thundershowers are also prevalent in the area. Rainfall intensities of over 2 inches per hour may occur in the months of June, July and August.

Appropriate measures are necessary to prevent deterioration of air and water quality, to reduce the possibility of sand blast damage to seedlings, and to avoid topsoil erosion. Recommendations are as follows:

a. Mulch treatment of all surface areas to stabilize soil surface particles. Mechanically treat soil surface to create matter roughness is also recommended. Some mulch material will require tucking in with a sheep's foot roller or disc. Extreme wind erosion problem areas may require jute matting.

b. Limited areas of high wind erosion potential may require a surface stabilizing agent such as poly vinyl acetate, asphalt emulsion, or styrene butodiene latex compounds. A rock mulch or wind deflecting structures may be used in conjunction with the surface stabilizing agents.

c. Slopes developed for topographic variation purposes should be short and have a flat area at their base to absorb minor amounts of runoff. Slopes longer than 15-30 feet should be avoided. Steep slopes should also be avoided.

d. Retention dams, dozer basins, contour ridges or small infiltration basins should be designed to avoid any possible runoff. Measures taken should assure a closed system to avoid any pollution discharge.

e. Haulage roads should have adequate protection from erosion and runoff by treatment of edges and sideslopes and construction of sediment traps.

10. Visibility

The computer-based visibility study indicated that many of the potential mining sites were visually inaccessible from Capitol Reef. A boom or crane 50 feet high or greater would be more visible from select sites in Capitol Reef or the Henry Mountains, but the visual resolution would not be great. The most visible features would be extensive areas of non-rehabilitated mined land on which the colors of the geologic materials and/or soil were different from adjacent surfaces. Recommendations to achieve a minimal visibility impact are:

a. Determine the long-distance perceived color of topsoil, geologic materials and any surface amendments in relation to non-disturbed areas and where practicable choose materials that provide a minimum differential or cover surfaces that do have a high color differential.

b. Avoid unnatural lines, contours and shapes in planning mining activities and rehabilitation.

c. Develop a revegetation plan that utilizes plant species similar in color, size, and shape to those of adjacent areas. Try to plant or seed in densities and species composition so as to be compatible visually with adjacent areas.

d. Determine exact sites such as scenic view points, tour areas, and any well-travelled roads which are important for recreation use in Capitol Reef and the Henry Mountains but which have a direct line of sight visibility to potential surface mined areas. (The visual prominence study was based only on mapped topographic points and did not include whether such points are used for recreation.)

11. Management of Planted Areas During Establishment of Vegetation and Early Plant Succession

Freedom from the adverse effects of grazing by livestock and wildlife -- especially rodents is vital to plant survival and growth under the harsh conditions of the coal area. Also important is protection from the abrasive effects of wind-blown sand and soil particles. Trampling effects from the feet of animals, humans or wheel traffic are also deleterious and should be prevented.

Under such difficult conditions as in the potential mining area, protection should be provided for a period of time sufficient for plant establishment (Valentine, 1971). Some of the recommendations are as follows:

a. Planted or seeded areas should be fenced to keep out livestock and big game animals. Depending on the size of the planted/seeded area a rodent proof addition to the lower part of the fence may be necessary.

b. Rodent repellents should be used if effective and available. If the seeded areas are irrigated,water should not be withdrawn until the seeded species have a sufficient root system to carry them through a normal dry period. In extremely dry periods limited amounts of water should be applied.

c. Wind shields or barriers may be necessary to prevent wind-blown particles from being driven into planted rehabilitation areas and causing sand-blasting of plant stems.

d. Flooding due to excessive runoff during short periods of intense rainfall should be avoided. Protective ridges and water spreading measures should be employed to prevent damage to newly established plants.

e. Livestock grazing and wildlife browsing should only be allowed after assurance that plants are large enough to withstand grazing use and limited trampling effects. This time may well not occur until 3-5 years after planting.

12. Detailed Research Needs

Many facets of the above recommendations for land rehabilitation of the Henry Mountains coal field are not sufficiently detailed to provide a basis for exact specifications. Although many guidelines can be drawn from a number of recent research projects on land rehabilitation and from an extensive literature on rangeland improvement, it is recommended that a number of problems be studied in greater depth to provide site-specific information. Recommended studies include the following:

a. Drill a test well to ascertain the quantity and quality of water that can be produced from a well in the Navajo Sandstone.

b. Study plant establishment methods suitable for arid or semi-arid sites. Particular emphasis should be placed on methods for propagation and outplanting of container-grown native plants especially drought and salt tolerant shrubs.

c. Develop methods for ecological or behavorial control of small animals that normally "raid" plots or fields of newly established plants.

d. Assess land use priorities for a suitable mix of land uses that would be optimum for the Henry Mountain coal field after mining.

e. Determine effective ways for reconstruction of a soil profile utilizing materials available to develop optimum stability, favorable soil moisture relations and ecosystem productivity.

f. Identify the actual use (or availability for use) of topographic elevations in Capitol Reef National Park in relation to visibility of the Henry Mountains coal field potential mining sites.

g. Determine mining methods appropriate for use in the Henry Mountain coal field in relation to the feasibility of separating the desirable strata or mixing all strata (except toxic layers) for use in rehabilitation and placement in a reconstructed profile.

h. Determine perennial plant cover, species composition, and plant density of the terrain that would be subjected to mining. This would serve as a guide for developing revegetation standards of performance.

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LITERATURE CITED

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VIII. APPENDIX

A. Detailed description of Geologic cores for holes 15, 3, 4, 5, 2, 1, 7. (In order of appearance from West to East.

B. Coal quality report prepared by Joe Hatch and Ronald Affalter, U. S. Geological Survey

C. Soil descriptions of units mapped by the USDA - Soil Conservation Service in their 1977 survey of the Henry Mountain coal resource area.

D. Computer-prepared maps showing visibility of various locations (Figure 43 shows the relative position of these points).

E. Scientific and common names of plants and animal referred to in the report.

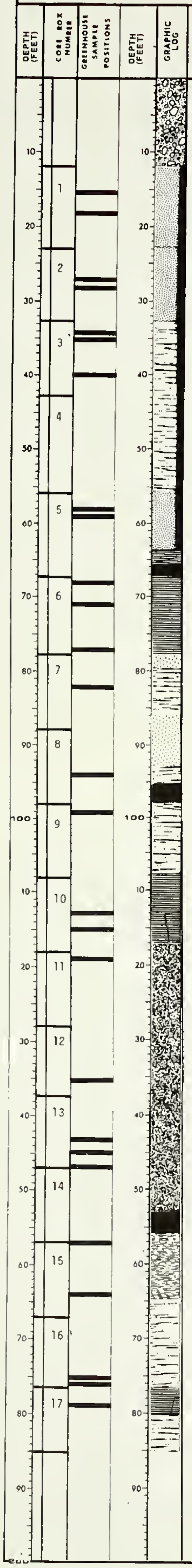
Appendix A.

Detailed descriptions of geologic cores for holes 15, 3, 4, 5, 2, 1, and 7. Listed in order of location from West to East on the study site.

GEOLOGIC LOG OF DRILL HOLE

SHEET 1 OF 12

FEATURE OVERBURDEN SAMPLING	PROJECT EMRIA STUDY OF THE HENRY MOUNTAINS COAL FIELD		STATE UTAH
HOLE NO. 1	LOCATION SWNE 17 T31S R9E	GROUND ELEV. 5840	TOTAL DEPTH 185 Feet
LOGGED BY J. STEWART WILLIAMS			



CLASSIFICATION AND PHYSICAL CONDITION

Pediment Gravel

Dusky-yellow to yellowish-gray sandstone, medium-grained; rock loose and core fragmented.

Same; increase in fines to be clayey sandstone.

Same; some laminae of scattered coaly fragments now leached.

Same.

56-64 dusky-yellow sandstone; 64-66 gray siltstone-claystone; 66-67.5 bone coal.

Siltstone-claystone grading into sandstone.

Gray sandstone to 80; then sandstone-claystone to 86; light-gray sandstone.

Light-gray sandstone becoming gray; 2' of dark-gray sandstone, partly bentonitic (?); then 2'9" of coal at bottom taken by USGS (Not reported to USU study group).

Dark-gray siltstone then mostly striped claystone-siltstone sandstone.

Gray siltstone-claystone to 117; then gray sandstone with laminae of organic material

Same sandstone; 118-120 lighter color, cleaner (?).

Same sandstone.

Same sandstone.

Same sandstone to 153; then coal and bone coal to 156; 156-157 siltstone becomes black, petroferous (?).

To 159 same siltstone; 165-167 gray claystone, blebs of lighter gray sandstone.

Striped sandstone-siltstone-claystone.

176.5-180 siltstone and bentontic claystone grading downward into striped gray sandstone with laminae of claystone (180-185).

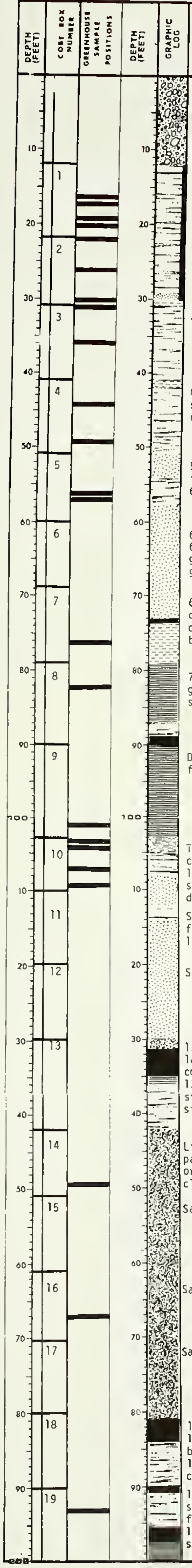
LEGEND

NO. ASSIGN TO ROCK TYPE	ROCK TYPE	SYMBOL
1	BUFF SANDSTONE	░
2	BUFF SANDSTONE WITH ORGANIC MATERIAL	▓
3	BUFF SANDSTONE WITH CLAYSTONE	☰
4	GRAY SANDSTONE	░
5	GRAY SANDSTONE WITH ORGANIC MATERIAL	▓
6	GRAY SANDSTONE WITH CLAYSTONE	☰
7	SHALE AND/OR CLAYSTONE	┄
8	SILTSTONE	▒
9	MUDSTONE OR CLAYSTONE-SILTSTONE	▤
10	COAL	■
11	GRAVEL OR OTHER REGOLITH	⁘

GEOLOGIC LOG OF DRILL HOLE

SHEET 2 OF 12

FEATURE OVERBURDEN SAMPLING
PROJECT EMRIA STUDY OF THE HENRY MOUNTAINS COAL FIELD
STATE UTAH
HOLE NO. 2
LOCATION NWNE 20 T31S R9E
GROUND ELEV. 5860
TOTAL DEPTH 214
LOGGED BY J. STEWART WILLIAMS'



CLASSIFICATION AND PHYSICAL CONDITION

Pediment gravels

12-15 yellowish-gray sandstone, some small clay blebs; 15-22 as below.

Sandstone-claystone intraformational conglomerate grading downward into light-gray sandstone at 29-30; 30-31 claystone, bentonitic.

Claystone-siltstone-sandstone, striped and conglomeratic.

Gray claystone at 41-42; then gray sandstone; laminae of claystone and organic matter.

51-54 gray sandstone; 54-58 claystone interbeds several inches thick; 58-60 gray sandstone.

60-64 fine-grained gray sandstone; 64-69 gray sandstone increasing in grain size to d 0.50 with frosted grains, dark grains 10%.

69-73 gray sandstone; 73-73.5 boney coal; 73.5-79 light to dark gray claystone, crumbly, probably bentomitic.

79-87 claystone grading into dark gray siltstone; 87-89 striped sandstone-claystone rock; 89-90 bone coal.

Dark-gray claystone grading into finely laminated gray siltstone.

To 105, medium-gray siltstone, then claystone-sandstone breccia to 108; 108-110 light-gray fine-grained sandstone, fairly well sorted, common d 0.25.

Same sandstone, probably increase in fines. 2" claystone bed at 111.5; 112-114 thin laminae of claystone.

Same sandstone common d 0.25.

130-131.5 light-gray sandstone, laminae of organic matter; then 3'4" coal taken by USGS; Sample 0189014, 135-136 dark gray siltstone and claystone; then striped claystone-sandstone.

Light-gray sandstone, cross-bedded in part; bedding marked with laminae of organic matter. Thin claybed at 141; clay blebs at 151.

Same sandstone.

Same sandstone.

Same sandstone.

180-181 light-gray sandstone, some laminae of coaly material; 181-184 bone coal and coal; then striped light-gray sandstone, dark-gray claystone and siltstone rock.

190-191 bone coal; 192-194 striped sandstone-claystone rock with intraformational breccia; coal at 195.5-197.5, then dark gray claystone and siltstone.

LEGEND

NO ASSIGN TO ROCK TYPE	ROCK TYPE	SYMBOL
1	BUFF SANDSTONE	░
2	BUFF SANDSTONE WITH ORGANIC MATERIAL	▒
3	BUFF SANDSTONE WITH CLAYSTONE	☰
4	GRAY SANDSTONE	░
5	GRAY SANDSTONE WITH ORGANIC MATERIAL	▒
6	GRAY SANDSTONE WITH CLAYSTONE	☰
7	SHALE AND/OR CLAYSTONE	┅
8	SILTSTONE	▒
9	MUDSTONE OR CLAYSTONE-SILTSTONE	▤
10	COAL	■
11	GRAVEL OR OTHER REGOLITH	∘

GEOLOGIC LOG OF DRILL HOLE

SHEET 3 OF 12

FEATURE: OVERBURDEN SAMPLING
PROJECT: EMRIA STUDY OF THE HENRY MOUNTAINS COAL FIELD
STATE: UTAH
HOLE NO.: 2
LOCATION: NWNE 20 T31S R9E
GROUND ELEV.: 5860
TOTAL DEPTH: 214
LOGGED BY: J. STEWART WILLIAMS

DEPTH (FEET)	CORE BOX NUMBER	GREENHOUSE SAMPLE POSITIONS	DEPTH (FEET)	GRAPHIC LOG	CLASSIFICATION AND PHYSICAL CONDITION
200	20	▬			Claystone laminae and blebs--90% of rock at 200. Seeds (?) at 200. Clay blebs decrease to 208.
10	21		10		Light-gray, fine-grained sandstone few (1%) dark grains.
20			20		
30			30		
40			40		
50			50		
60			60		
70			70		
80			80		
90			90		
300					

LEGEND

NO ASSIGN TO ROCK TYPE	ROCK TYPE	SYMBOL
1	BUFF SANDSTONE	▌
2	BUFF SANDSTONE WITH ORGANIC MATERIAL	▨
3	BUFF SANDSTONE WITH CLAYSTONE	☰
4	GRAY SANDSTONE	░
5	GRAY SANDSTONE WITH ORGANIC MATERIAL	▒
6	GRAY SANDSTONE WITH CLAYSTONE	☰
7	SHALE AND/OR CLAYSTONE	┅
8	SILTSTONE	▒
9	MUDSTONE OR CLAYSTONE-SILTSTONE	▤
10	COAL	■
11	GRAVEL OR OTHER REGOLITH	⁘

PROJECT: EMRIA STUDY STATE: UTAH SHEET 3 OF 12 HOLE NO. 2

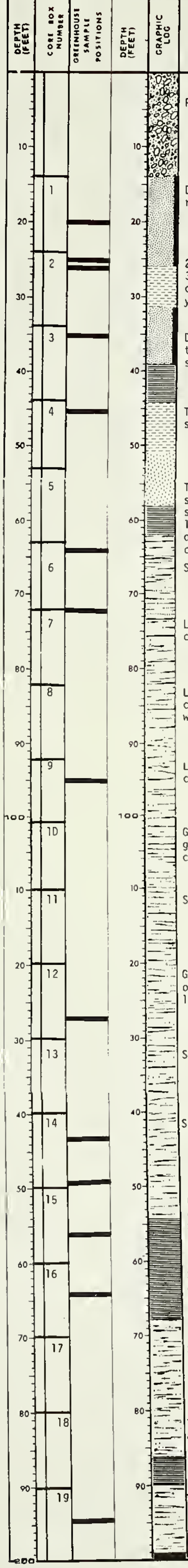
GEOLOGIC LOG OF DRILL HOLE

SHEET 4 OF 12

FEATURE OVERBURDEN SAMPLING PROJECT EMRIA STUDY OF THE HENRY MOUNTAINS COAL FIELD STATE UTAH

HOLE NO. 3 LOCATION NESW 18 T31S R9E GROUND ELEV. 5830 TOTAL DEPTH 290

LOGGED BY J. STEWART WILLIAMS FIRST OF TWO PAGES FOR HOLE NO. 3



CORE BOX NUMBER	CLASSIFICATION AND PHYSICAL CONDITION
	Pediment gravel.
1	Dusky-yellow sandstone, with gympsum rosettes (?) as small white patches.
2	24-26, dusky yellow sandstone; 26-31.5 light-gray to yellowish-gray claystone, leached; 31.5-34, dusky-yellow sandstone with concretions.
3	Dusky-yellow fine-grained sandstone to 39; to 44, dark gray claystone-siltstone.
4	To 51, dark-gray claystone; then sandstone.
5	To 58, fine-grained light-gray sandstone grading down into 4' gray siltstone-claystone then gray sandstone laminated with gray claystone and/or organic material. One 6" unit of claystone.
6	Same sandstone.
7	Light-gray sandstone with laminae of claystone or organic material.
8	Laminated and brecciated sandstone-claystone, beginning in first foot with light-gray sandstone.
9	Laminated and brecciated sandstone-claystone.
10	Gray sandstone with laminae of dark-gray claystone; thin units (6") of claystone.
11	Same.
12	Gray sandstone with thin laminae of organic material; blebs and thin layers of claystone.
13	Same gray sandstone.
14	Same sandstone.
15	Gray sandstone to 154; black carbonaceous shale grading into dark-gray siltstone.
16	Same siltstone to 168; then laminated and brecciated siltstone-sandstone.
17	Same siltstone-sandstone.
18	To 186.5, sandstone-siltstone breccia and laminae, then claystone-siltstone.
19	To 199, claystone-sandstone, dark gray; some thin laminae of sandstone; 199-200, coal taken by USGS.

LEGEND

NO. ASSIGN TO ROCK TYPE	ROCK TYPE	SYMBOL
1	BUFF SANDSTONE	▨
2	BUFF SANDSTONE WITH ORGANIC MATERIAL	▨
3	BUFF SANDSTONE WITH CLAYSTONE	▤
4	GRAY SANDSTONE	░
5	GRAY SANDSTONE WITH ORGANIC MATERIAL	▨
6	GRAY SANDSTONE WITH CLAYSTONE	▤
7	SHALE AND/OR CLAYSTONE	▤
8	SILTSTONE	▨
9	MUDSTONE OR CLAYSTONE-SILTSTONE	▤
10	COAL	■
11	GRAVEL OR OTHER REGOLITH	▨

GEOLOGIC LOG OF DRILL HOLE

SHEET 5 OF 12

FEATURE OVERBURDEN SAMPLING
PROJECT EMRIA STUDY OF THE HENRY MOUNTAINS COAL FIELD
STATE UTAH
HOLE NO 3
LOCATION NESW 18 T31S R9E
GROUND ELEV. 5830
TOTAL DEPTH 290
LOGGED BY J. STEWART WILLIAMS
SECOND OF TWO PAGES FOR HOLE NO. 3

CLASSIFICATION AND PHYSICAL CONDITION

To 206, 5'10" coal taken by USGS. Sample 0189D15. Then to 209, dark-gray siltstone and claystone; 209-211, boney coal.

To 212, dark-gray claystone, then grading into gray sandstone.

Gray sandstone; thin laminae of organic material.

To 235, gray sandstone; then intraformational conglomerate with coal and sandstone 3", coal 17", sandstone 2", bone coal 1'.

6" coal, then intraformational breccia with gray sandstone.

To 251, same breccia; 251-253, laminated siltstone; then 21" coal taken by USGS. Sample D189016. 255-260, claystone grading into laminated dark-gray siltstone.

Medium-gray siltstone laminated with claystone.

To 275, same siltstone-claystone; then grading downward into light-gray fine-grained sandstone.

Same sandstone.

LEGEND

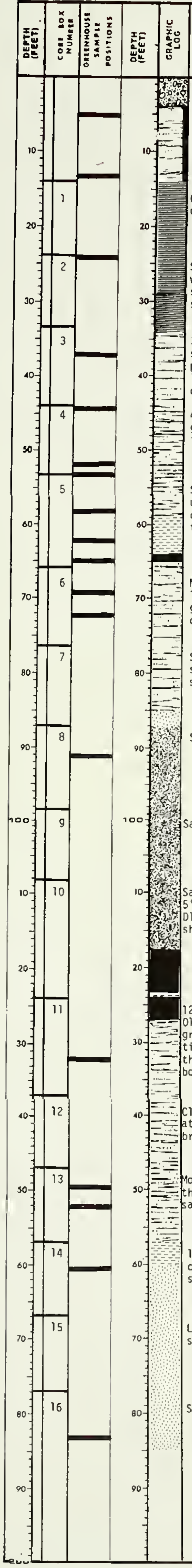
NO ASSIGN TO ROCK TYPE	ROCK TYPE	SYMBOL
1	BUFF SANDSTONE	░
2	BUFF SANDSTONE WITH ORGANIC MATERIAL	▓
3	BUFF SANDSTONE WITH CLAYSTONE	☰
4	GRAY SANDSTONE	░
5	GRAY SANDSTONE WITH ORGANIC MATERIAL	▓
6	GRAY SANDSTONE WITH CLAYSTONE	☰
7	SHALE AND/OR CLAYSTONE	▤
8	SILTSTONE	▦
9	MUDSTONE OR CLAYSTONE-SILTSTONE	▥
10	COAL	■
11	GRAVEL OR OTHER REGOLITH	○

PROJECT EMRIA STUDY STATE UTAH SHEET 5 OF 12 HOLE NO 3

GEOLOGIC LOG OF DRILL HOLE

SHEET 6 OF 12

FEATURE OVERBURDEN SAMPLING PROJECT EMRIA STUDY OF THE HENRY MOUNTAINS COAL FIELD STATE UTAH
HOLE NO. 4 LOCATION SWSE 19 R9E GROUND ELEV. 5740 TOTAL DEPTH 185
LOGGED BY J. STEWART WILLIAMS



CLASSIFICATION AND PHYSICAL CONDITION

Regolith

Dusky yellow sandstone, poorly sorted grains from 0.1 to 0.5, interlayered with medium light-gray claystone; laminae and seams of coaly material.

Claystone grading into siltstone; both often stained buff in color.

Same to 29; there buff colors give way to gray; 29-34 medium-gray claystone with laminae of lighter gray siltstone and fine-grained sandstone.

34-39, interlayered gray fine-grained sandstone and medium-gray claystone, probably bentonitic; 39-44 medium to light-gray sandstone with scattered clay blebs.

44-46, same; below sandstone darker gray, salt and pepper, due to increase in dark grains to 10%.

Same, increase in grain size to 0.5 up to 59; then medium-gray bentonitic claystone to 64; then coal 1 foot; then claystone to 66.

Medium-gray claystone grading into lighter gray siltstone and fine-grained sandstone, thin units of carbonaceous shale.

Same to 83; 85-87 increasing grain size to 0.5-0.25; salt and pepper sandstone with 5-10% dark grains.

Same; some laminae of coaly material.

Same.

Same sandstone to 117'9", then coal 5'5" taken by USGS to 123'2". Sample D189017. Then dark-gray carbonaceous shale to 124.

124-127 coal taken by USGS. Sample 0189018. Then mostly siltstone grading into claystone in one direction, into fine-grained sandstone in the other; 135-136 bone coal or carbonaceous shale.

Claystone-siltstone-sandstone laminated and with intraformational breccia.

Mostly medium-gray claystone grading through siltstone into light gray sandstone.

157-160, claystone grading into bone coal, then abrupt change to gray sandstone.

Limit to medium gray fine-grained sandstone.

Same sandstone.

LEGEND

NO. ASSIGN TO ROCK TYPE	ROCK TYPE	SYMBOL
1	BUFF SANDSTONE	▨
2	BUFF SANDSTONE WITH ORGANIC MATERIAL	▨
3	BUFF SANDSTONE WITH CLAYSTONE	▤
4	GRAY SANDSTONE	░
5	GRAY SANDSTONE WITH ORGANIC MATERIAL	▒
6	GRAY SANDSTONE WITH CLAYSTONE	▤
7	SHALE AND/OR CLAYSTONE	▤
8	SILTSTONE	▓
9	MUDSTONE OR CLAYSTONE-SILTSTONE	▤
10	COAL	■
11	GRAVEL OR OTHER REGOLITH	▩

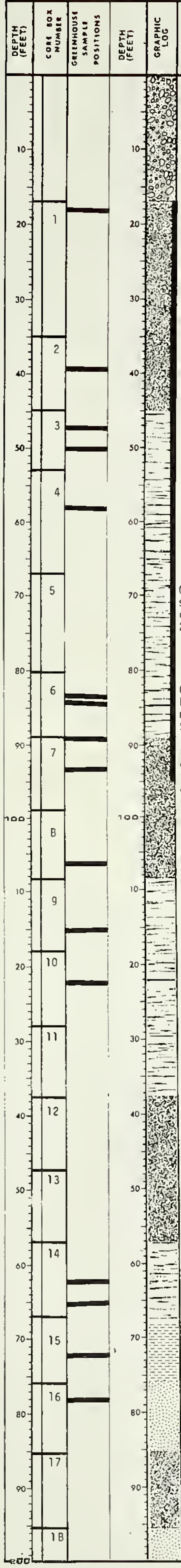
PROJECT EMRIA STUDY STATE UTAH SHEET 6 OF 12 HOLE NO. 4

GEOLOGIC LOG OF DRILL HOLE

SHEET 7 OF 12

FEATURE OVERBURDEN SAMPLING
PROJECT EMRIA STUDY OF THE HENRY MOUNTAINS COAL FIELD
STATE UTAH
HOLE NO. 5
LOCATION SWNW 20 T31S R9E
GROUND ELEV. 5910
TOTAL DEPTH 304
LOGGED BY J. STEWART WILLIAMS

FIRST OF TWO PAGES FOR HOLE NO. 5



CLASSIFICATION AND PHYSICAL CONDITION

Pediment gravel; cobbles of diorite porphyry.

Sandstone; dusky-yellow, fine-grained d 0.1; limonite stains, leached organic fragments 30-31; also 34-37.

Same; 39-40 thin laminae of dark material, sooty, organic with platy material (mica? gypsum?) providing smooth partings on the cores; 43-46 increase in grain size to d 0.25, still dusky yellow.

Same; 46-47 gray ironstone concretion 47-48 gray clay blebs.

53-59, clay blebs increasing to be 50% of rock; grain size at 67 d 0.1 with some finer.

Generally same sandstone but particle size decreasing and about 10% gray clay in blebs or thin layers up to 2-3" thick.

Generally same, except core tends to be laminated with partings of platy material of fine organic (?) material Same clay blebs.

Disappearance of clay blebs; back to dusky yellow fine-grained sandstone; thin laminae of coaly material at 93 and 95; general color change at 93 to grayer (yellowish gray); grain size d .01 and finer = silty sandstone.

Finely laminated gray sandstone, light-gray to very light-gray; bedding marked by thin laminae of coaly material and clay; varied cross-bedding with fine detail.

Light-gray fine-grained sandstone with clay laminae and clay blebs; same fine laminations as in Box 8.

Generally same; clay blebs up to 50% at 120-122, tapering off to near none at 128.

Generally same to 133; then sandstone becomes lighter in color (very light gray) and coarser in grain size, d 0.25.

Light gray, medium grained sandstone d 0.25; relatively clean, cross-bedding marked by thin laminae of organic material.

Same; gray particles in sand are pyroxene (?).

Medium grained d 0.25 very light-gray sandstone; increasing slightly in grain size to 162 then strongly cross-bedded with dark gray clay fragments and lighter gray hard fragments of silicified siltstone; coal particles or fragments on end.

Sandstone to 168; then dark-gray clay to 174, then gray sandstone.

Light-gray to very light-gray sandstone, medium grained d 0.25, cross-bedded with 5% darker grains arranged in laminae.

Same as in Box 16. More continuous dark laminae of coaly material.

195.5-197.5 very light gray sandstone: 197.5-200 light-gray sandstone: 200-203, coaly layers increase; 203-205 very light-gray sandstone.

LEGEND

NO. ASSIGN TO ROCK TYPE	ROCK TYPE	SYMBOL
1	BUFF SANDSTONE	░
2	BUFF SANDSTONE WITH ORGANIC MATERIAL	▒
3	BUFF SANDSTONE WITH CLAYSTONE	☰
4	GRAY SANDSTONE	░
5	GRAY SANDSTONE WITH ORGANIC MATERIAL	▒
6	GRAY SANDSTONE WITH CLAYSTONE	☰
7	SHALE AND/OR CLAYSTONE	┄
8	SILTSTONE	▓
9	MUDSTONE OR CLAYSTONE-SILTSTONE	▤
10	COAL	■
11	GRAVEL OR OTHER REGOLITH	⁘

GEOLOGIC LOG OF DRILL HOLE

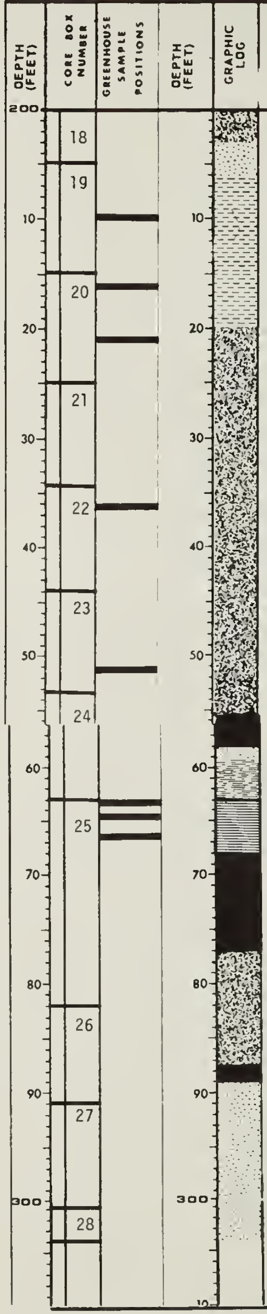
SHEET 8 OF 1

FEATURE OVERBURDEN SAMPLING PROJECT OF THE HENRY MOUNTAINS COAL FIELD STATE

HOLE NO. 5 LOCATION SWNW 20 T31S R9E GROUND ELEV. 5910 TOTAL DEPTH 304

LOGGED BY J. STEWART WILLIAMS

SECOND OF TWO PAGES FOR HOLE NO. 5



CLASSIFICATION AND PHYSICAL CONDITION

205-206, very light-gray sandstone; 206-210 dark-gray shale with coal fragments; 210-214 black carbonaceous shale with carbonized wood fragments.

215-220 dark-gray shale; 220-221 shale grading through siltstone into gray sandstone.

Very light-gray to gray sandstone, with carbonaceous laminae as above.

Same sandstone as above; medium grained d 0.25; same carbonaceous laminae often in cross beds.

Same sandstone as above; carbonaceous laminae with micaceous mineral at 248.

253.5-255.5 gray sandstone; 255.5-256.5 coal; 256.5-257.5 coal interbedded with gray carbonaceous shale grading to gray sandstone at 258; gray siltstone streaked with carbonaceous material to 263.

263-270, dark-gray siltstone and shale with coal, USGS Sample D189012, 5' of core for 7' of hole; 270' 280, 3' of core mostly gray sandstone, coal lost.

Gray sandstone as above, 282-287.5 gray sandstone streaked with carbonaceous material; 287.5-289 coal; 289-291 light-gray sandstone.

Sandstone, very light-gray to light-gray, fine to medium grained, carbonaceous streaks absent generally.

Very light-gray sandstone.

LEGEND

NO ASSIGN TO ROCK TYPE	ROCK TYPE	SYMBOL
1	BUFF SANDSTONE	▯
2	BUFF SANDSTONE WITH ORGANIC MATERIAL	▩
3	BUFF SANDSTONE WITH CLAYSTONE	☰
4	GRAY SANDSTONE	⋮
5	GRAY SANDSTONE WITH ORGANIC MATERIAL	▩
6	GRAY SANDSTONE WITH CLAYSTONE	☰
7	SHALE AND/OR CLAYSTONE	▤
8	SILTSTONE	▦
9	MUDSTONE OR CLAYSTONE-SILTSTONE	▥
10	COAL	■
11	GRAVEL OR OTHER REGOLITH	⁘

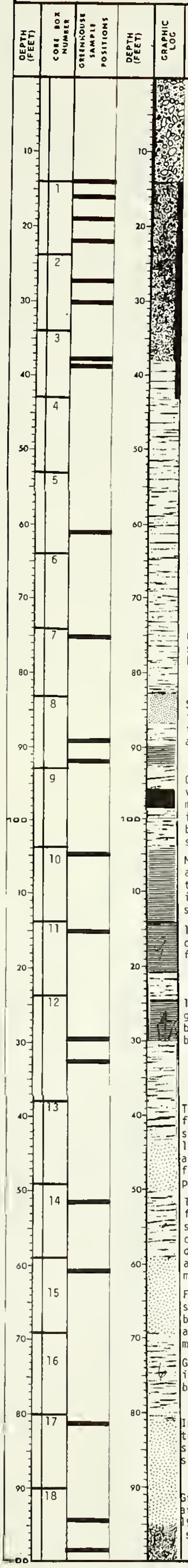
PROJECT EMRIA STUDY ... STATE UTAH ..... SHEET 8 OF 12 HOLE NO 5

GEOLOGIC LOG OF DRILL HOLE

SHEET 9 OF 12

FEATURE: OVERBURDEN SAMPLING
PROJECT: EMRIA STUDY OF THE HENRY MOUNTAINS COAL FIELD
STATE: UTAH
HOLE NO.: 7
LOCATION: SWSW 21 T31S R9E
GROUND ELEV.: 6030
TOTAL DEPTH: 295
LOGGED BY: J. STEWART WILLIAMS

FIRST PAGE FOR HOLE NO. 7



CLASSIFICATION AND PHYSICAL CONDITION

Pediment gravel.

Grayish-orange very fine-grained sandstone, some mica, dark grains oxidized to limonite; cross-bedded laminae of small coaly fragments.

Generally same; 26-29 coaly material increased; 30-34 dark grains not oxidized, color lighter, yellowish-gray.

Generally same; little coaly material clay bleb intraformational conglomerate at 38 and at 42; some ironstone concretions.

Same conglomerate to 47, then striped intricately cross-bedded gray sandstone with laminae of dark gray claystone; at 53, 80% claystone.

Same, claystone varies from 10% to 80%.

Same; some cross bedding nearly vertical.

Claystone laminae decreased to occasional occurrence; some claystone bleb intraformational conglomerate.

Sandstone clear to 87, then increasing claystone blebs at 90, then change to dark-gray claystone and siltstone.

Claystone and siltstone, short intervals sandstone increases; plant material, roots (?), stems (?) increases: 102-104 intricate cross-bedding and flowage structures. Coal samples USGS, 96'-98'9" No. 0189013.

Medium dark gray mudstone, siltstone and claystone, with plant fragments to 120'6", then mudstone interlayered irregularly with gray fine-grained sandstone.

124.6-130, 2' only of fragmented core, gray claystone with plant fragments.

130-135 siltstone grading into fine-grained sandstone; minute contorted bedding; claystone layers, core breaks on these.

To 140, same, with increasing very fine sand; 140-143.5 mostly claystone, core fragmented, partly lost; 143.5-149.5, very fine-grained and and fine-grained sandstone, light, friable, core fragmented; "salt and pepper", 5% (?) dark grains.

To 150, gray sandstone, then intraformational conglomerate to claystone; then back to interbedded, cross-bedded light gray sandstone, dark gray siltstone and claystone, as above; thin black layers of coaly material.

Fine grained gray salt and pepper sandstone, at 164 intraformational breccia with fragments of mudstone; also at 167; at 168 cross-bedding marked with organic laminae.

Gray sandstone, dark-gray mudstone, intraformational conglomerate; cross-bedding.

Intraformational-conglomerate to 181; to 184 light gray fine-grained sandstone; 184-190, increase in grain size to 0.5.

Grain size to 0.5 continues to 196; at 195 increase in coaly material; 195-200 decreased grain size to siltstone and fine sandstone.

LEGEND

NO. ASSIGN TO ROCK TYPE	ROCK TYPE	SYMBOL
1	BUFF SANDSTONE	▨
2	BUFF SANDSTONE WITH ORGANIC MATERIAL	▨
3	BUFF SANDSTONE WITH CLAYSTONE	▤
4	GRAY SANDSTONE	▨
5	GRAY SANDSTONE WITH ORGANIC MATERIAL	▨
6	GRAY SANDSTONE WITH CLAYSTONE	▤
7	SHALE AND/OR CLAYSTONE	▤
8	SILTSTONE	▨
9	MUDSTONE OR CLAYSTONE-SILTSTONE	▤
10	COAL	■
11	GRAVEL OR OTHER REGOLITH	▨

GEOLOGIC LOG OF DRILL HOLE

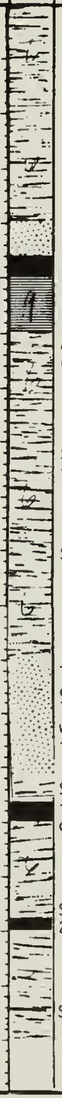
SHEET 10 OF 12

FEATURE OVERBURDEN SAMPLING PROJECT EMRIA STUDY OF THE HENRY MOUNTAINS COAL FIELD STATE UTAH
HOLE NO. 7 LOCATION SWSW 21 T31S R9E GROUND ELEV. 6030 TOTAL DEPTH 295
LOGGED BY J. STEWART WILLIAMS

SECOND PAGE FOR HOLE NO. 7

DEPTH (FEET)	CORE BOX NUMBER	GREENHOUSE SAMPLE POSITIONS	CLASSIFICATION AND PHYSICAL CONDITION
200	19		Fine-grained sandstone and siltstone, intricate cross-bedding as above, laminae of coaly material.
10	20		Striped, cross-bedded sandstone-siltstone-claystone. Laminae of siltstone-claystone and sandstone.
20	21	— —	220-223 salt and pepper sandstone, coarser grained, d 0.25 to 0.50. 223-225, coal; gray claystone grading to gray siltstone at 230.
30	22		Again striped sandstone-siltstone-claystone.
40	23		Same striped rock; sandstone compared to finer materials 50-50%.
50	24		Same.
60	25	—	To 263, gray sandstone, appearing dark gray in core; 263-271, sandstone, light-gray to dark-gray, some striping with claystone laminae; some intraformational conglomerate.
70	26		Sandstone-siltstone-claystone intraformational conglomerate; 273-275 coal.
80	27		Same intraformational conglomerate; 284-285 carbonaceous shale to coal.
90	28		Striped sandstone-claystone.
300			

GRAPHIC LOG



LEGEND

NO. ASSIGN TO ROCK TYPE	ROCK TYPE	SYMBOL
1	BUFF SANDSTONE	▌
2	BUFF SANOSTONE WITH ORGANIC MATERIAL	▨
3	8UFF SANDSTONE WITH CLAYSTONE	☰
4	GRAY SANOSTONE	⠿
5	GRAY SANDSTONE WITH ORGANIC MATERIAL	▩
6	GRAY SANDSTONE WITH CLAYSTONE	☰
7	SHALE ANO/OR CLAYSTONE	░
8	SILTSTONE	▒
9	MUDSTONE OR CLAYSTONE-SILTSTONE	▤
10	COAL	■
11	GRAVEL OR OTHER REGOLITH	⁘

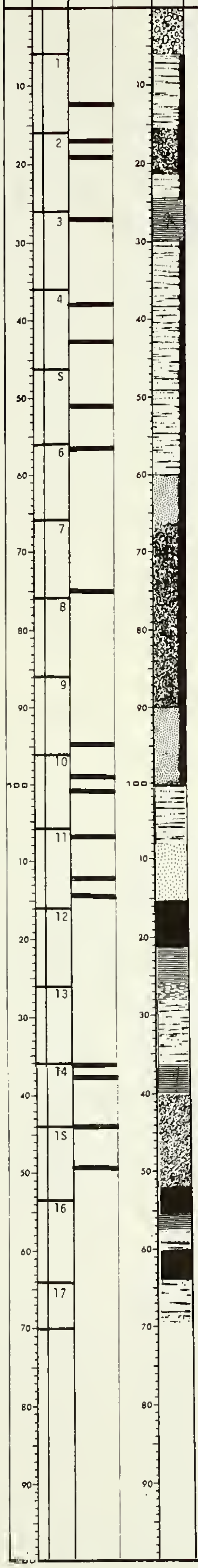
PROJECT EMRIA STUDY STATE UTAH SHEET 10 OF 12 HOLE NO. 7

GEOLOGIC LOG OF DRILL HOLE

SHEET 11 OF 12

FEATURE: OVERBURDEN SAMPLING
PROJECT: EMRIA STUDY OF THE HENRY MOUNTAINS COAL FIELD
STATE: UTAH
HOLE NO.: 9
LOCATION: SENW 22 T31S R8E
GROUND ELEV.: S740
TOTAL DEPTH: 170
LOGGED BY: J. STEWART WILLIAMS

DEPTH (FEET) | CORE BOX NUMBER | GREENHOUSE SAMPLE POSITIONS | DEPTH (FEET) | GRAPHIC LOG | CLASSIFICATION AND PHYSICAL CONDITION



Regolith

Medium-gray claystone, partly stained yellowish-gray, interlayered with fine-grained buff sandstone, 6-10; 10-1S mostly sandstone with minor claystone; 1S-16 sandstone.

16-21 buff sandstone with laminae of coaly material; 21-24 sandstone interlayered with claystone.

24-30, light-gray claystone and siltstone; 30-36 light-gray siltstone and sandstone, fine-grained and intricately bedded with laminae of coaly material.

Same to 40; then mostly fine-grained buff sandstone with scattered thin beds of claystone, and laminae of coaly material.

To 60 same; particles of amber common in layers of organic material 60-66 mostly buff fine-grained sandstone.

Same sandstone, thin laminae of organic material.

Buff sandstone with laminae of organic material at 79'6" bed of gray claystone-siltstone.

To 90, same sandstone, 90-94 medium-grained sandstone, still buff but salt and pepper. To 96 buff fine-grained sandstone.

To 100, same buff sandstone; 100-106, gray siltstone interbeds increase.

Sandstone-claystone intraformational conglomerate to 108; then gray sandstone to 11S, giving way to coal.

Coal to 121: to 122, gray claystone-siltstone; to 126 gray siltstone. USGS Sample 0189019.

To 128 gray siltstone grading downward into fine-grained sandstone-siltstone interlaminated.

To 138 gray claystone and siltstone grading below 140 into gray, fine-grained sandstone with laminae of organic material.

To 1S2, same sandstone, then abrupt contact with coal to 1S3.5. USGS Sample 0189020.

Coal to 155.5 then 2' black carbonaceous siltstone-claystone; then 3' laminated claystone-siltstone-sandstone, then 160-164 boney coal grading into carbonaceous shale. USGS Sample 0189021.

Claystone-siltstone, and sandstone interlayered with much organic material.

LEGEND

NO. ASSIGN TO ROCK TYPE	ROCK TYPE	SYMBOL
1	BUFF SANDSTONE	░
2	BUFF SANDSTONE WITH ORGANIC MATERIAL	▒
3	BUFF SANDSTONE WITH CLAYSTONE	☰
4	GRAY SANDSTONE	░
S	GRAY SANDSTONE WITH ORGANIC MATERIAL	▒
6	GRAY SANDSTONE WITH CLAYSTONE	☰
7	SHALE AND/OR CLAYSTONE	┄
8	SILTSTONE	▒
9	MUDSTONE OR CLAYSTONE-SILTSTONE	▤
10	COAL	■
11	GRAVEL OR OTHER REGOLITH	▓

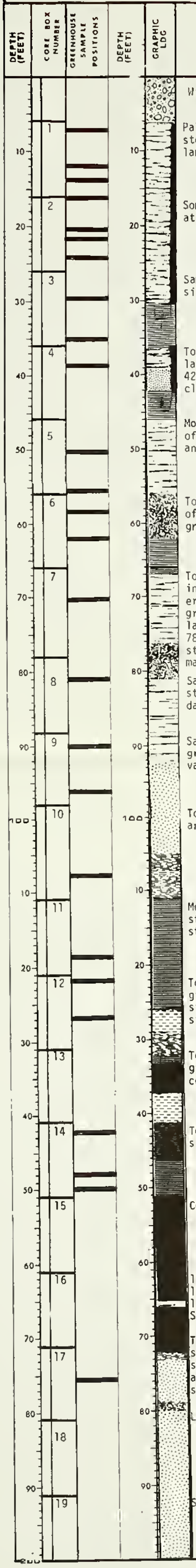
GEOLOGIC LOG OF DRILL HOLE

SHEET 12 OF 12

FEATURE OVERBURDEN SAMPLING PROJECT EMRIA STUDY OF THE HENRY MOUNTAINS COAL FIELD STATE UTAH

HOLE NO. 15 LOCATION SWSW23 T31S R8E GROUND ELEV. 5680 TOTAL DEPTH 200

LOGGED BY J. STEWART WILLIAMS



CLASSIFICATION AND PHYSICAL CONDITION

Wind-blown silt.

Pale-yellowish, fine-grained sandstone; scattered clay blebs, some laminae of organic material.

Some sandstone becoming finer grained at bottom.

Same sandstone to 30.5, then gray siltstone-claystone.

To 39, siltstone-sandstone interlaminated; 39-42 buff sandstone; 42-46 gray interbedded siltstone-claystone.

Mostly gray sandstone with laminae of organic material, also clay blebs and some beds of claystone.

To 62, gray sandstone with laminae of coaly material; 62-66 mostly gray claystone grading into siltstone

To 71, light-gray siltstone grading into fine-grained sandstone, considerable coaly material; to 76, fine-grained light-gray sandstone with laminae of dark-gray claystone; 76-78, light gray fine-grained sandstone with thin laminae of coaly material.

Same to 81; 81-86 light-gray sandstone with laminae and blebs of dark-gray claystone.

Same sandstone to 92; 92-98 coarser grained sandstone; salt and pepper variety, with 10% dark grains.

To 105, same sandstone, then light and dark gray siltstone.

Medium-gray to medium dark-gray siltstone, thinly laminated with claystone.

To 126, medium light-gray siltstone grading at 126 into dark gray claystone; 129-131, medium-gray siltstone.

To 132, same siltstone then 1' dark-gray claystone, then 4' coal and bone coal, then dark-gray claystone.

To 146 medium-gray siltstone; then siltstone and claystone interlayered.

Coal. USGS Sample 0189022

161-165 coal. USGS Sample 0189023; 165-166 sandstone-siltstone interlaminated; then coal to 171. USGS Sample 0189024.

To 172, coal; to 173 dark-gray siltstone; to 179 light-gray fine-grained sandstone; 179-180, breccia of coal and light-gray sandstone; 180-181 sandstone.

Light-gray fine-grained sandstone.

Same sandstone.

LEGEND

NO. ASSIGN TO ROCK TYPE	ROCK TYPE	SYMBOL
1	BUFF SANDSTONE	▨
2	BUFF SANDSTONE WITH ORGANIC MATERIAL	▨
3	BUFF SANDSTONE WITH CLAYSTONE	▤
4	GRAY SANDSTONE	░
5	GRAY SANDSTONE WITH ORGANIC MATERIAL	▓
6	GRAY SANDSTONE WITH CLAYSTONE	▤
7	SHALE AND/OR CLAYSTONE	▤
8	SILTSTONE	▨
9	MUDSTONE OR CLAYSTONE-SILTSTONE	▤
10	COAL	■
11	GRAVEL OR OTHER REGOLITH	▩

Appendix B.

Coal Quality Henry Mountains Field EMRIA Study Area

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(References for this appendix may be found at the end of this report).

Coal Quality

Thirteen coal samples were collected from the eight core holes in the Henry Mountains field EMRIA study area by the U.S. Geological Survey. These samples are briefly described in table D1. Proximate and ultimate analyses, heat content, air-dried-loss, forms-of-sulfur and ash-fusion temperature determinations on these samples were provided by the Coal Analysis Section, U.S. Bureau of Mines, Pittsburgh, Pennsylvania. These analyses are listed in table D2. The U.S. Geological Survey in Denver, Colorado provided analyses on these samples for 32 major and minor oxides and trace elements in coal ash (table D3) and analyses of nine trace elements in whole coal (table D4). Analytical procedures used by the U.S. Geological Survey are described in Swanson and Huffman (1976). Table D5 contains the data listed in table D3 converted to a whole coal basis and the data listed in table D4. Twenty five additional elements were looked for but not found in amounts greater than their lower limits of detection (table D6). Statistical summaries of the U.S. Bureau of Mines and the U.S. Geological Survey data are listed in tables D7, D8, and D9.

In this report the geometric mean (GM) is used as the estimate of the most probable concentration (mode); the geometric mean is the antilog of the mean of the logrithm of concentration. The measure of scatter about the mode used here is the geometric deviation (GD) which is the antilog of the standard deviation of the logarithms of concentration. These statistics are used because of the common tendency for the amounts of trace elements in natural materials to exhibit positively skewed frequency distributions; these distributions are normalized by analyzing and summarizing trace element data on a logarithmic basis.

If the frequency distributions are lognormal the geometric mean is the best estimate of the mode, and the estimated range of the central two-thirds of the observed distribution has a lower limit equal to GM/GD and an upper limit equal to GM·GD. The estimated range of the central 95 percent of the observed distribution has a lower limit equal to $GM/(GD)^2$ and an upper limit equal to $GM\cdot(GD)^2$ (Connor and others, 1976).

Although the geometric mean is, in general, an adequate estimate of the most common concentration, it is, nevertheless, a biased estimate of the arithmetic mean. In the summary tables of data, the estimates of the arithmetic means are Sichel's <u>t</u> statistic (Miesch, 1967). In this report the terms arithmetic mean, and average value, are used synonymously.

A common problem in statistical summaries of trace element data arises when the element concentration in one or more of the samples is below the limit of analytical detection, resulting in a censored distribution. Procedures developed by Cohen (1959) were used to compute unbiased estimates of the geometric mean, geometric deviation, and arithmetic mean where the concentration data are censored.

According to ASTM designation D388-66 the apparent rank of coal samples collected in the Henry Mountains EMRIA study area is subbituminous A coal. For comparison the apparent rank indicated by 13 analyses of mined coal from the Wasatch Plateau field in Central Utah (table D7) is high-volatile B bituminous coal. The coal from the Wasatch Plateau field was selected for comparison with the samples collected from the Henry Mountains study area because most of the major producing mines in Utah are located in the Wasatch Plateau field. Because of the higher rank of the Wasatch Plateau field coal, average moisture and oxygen contents of this coal are appreciably lower while average volatile matter, fixed carbon, carbon and heat content are appreciably higher when compared to Henry Mountains field coal. Average ash, sulfur and pyritic sulfur contents of coal from the Henry Mountains field are appreciably higher while nitrogen contents are appreciably lower than those in the Wasatch Plateau field coal. Contents of hydrogen, sulfate sulfur and organic sulfur are similar in the two sets.

A comparison of the average contents of ash and nine oxides in the laboratory ash of 13 coal samples from the Hanry Mountains EMRIA study area with average contents in the laboratory ash of 48 Wasatch Plateau field coal samples (table D8) shows that CaO, MgO, and SO_3 contents are higher by more than 50 percent in the Henry Mountains field coal and Na_2O is higher by more than 50 percent in the Wasatch Plateau field coal. Ash, SiO_2, Al_2O_3, K_2O, Fe_2O_3, and TiO_2 contents are about the same in these two sets.

A comparison of the average contents of 27 trace elements in 13 Henry Mountains field coal samples with 48 coal samples from the Wasatch Plateau field (table D9) shows that B, Ba, Mn, Sb, U, and Y are higher by factors of between two and three in the Henry Mountains coal. Contents of the other 21 trace elements in the two sets are similar.

Correlation coefficients generated from this set of data shows the following geochemical association:

(1) Elements such as Si, K, Ti, Al, U, Zr, Ga are positively correlated with each other, as are B, Ca and Na. These elements are lithophile in nature and generally occur associated with alumino silicate minerals.

(2) Elements such as Fe, Mo, As, Hg show positively correlations with each other. These elements are generally chalcophile and may be associated with sulfides in the coal. Only positive correlation coefficients greater than 0.60 were used to determine geochemical association.

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Table B-1--USGS sample number, hole number, location, depth interval, and description of 13 coal samples from the Henry Mountain field, Garfield County, Utah.

[All samples are from the Emery Formation of Cretaceous age. 1 meter = 3.28 ft.]

USGS sample number	Hole number	Location	Depth interval (meters)	Description
D189013	1	SWNE sec. 17, T. 31 S., R. 9 E.	29.24 - 30.07	Coal, with coaly shale partings.
D189014	2	NWNE sec. 20, T. 31 S., R. 9 E.	40.31 - 41.33	Coal, with minor pyrite and amber.
D189015	3	SWSE sec. 18, T. 31 S., R. 9 E.	60.66 - 62.43	Coal.
D189016	--do--	---------------do---------------	77.50 - 78.03	Coal and bone coal.
D189017	4	SWSE sec. 19, T. 31 S., R. 9 E.	35.89 - 37.54	Coal.
D189018	--do--	---------------do---------------	37.80 - 38.71	Coal, bright and banded with minor pyrite.
D189012	5	SWNW sec. 20, T. 31 S., R. 9 E.	81.58 - 82.20	Coal, with large amounts of pyrite.
D189019	9	SENW sec. 22, T. 31 S., R. 8 E.	35.05 - 36.88	Coal, bright and banded, with disseminated pyrite and minor amber.
D189020	--do--	---------------do---------------	46.33 - 47.40	Coal, with numerous carb shale partings and minor pyrite.
D189021	9	SENW sec. 22, T. 31 S., R. 8 E.	48.77 - 49.99	Coal, with shaly coal and silty carb shale.
D189022	15	SESW sec. 23, T. 31 S., R. 8 E.	46.02 - 48.08	Coal, bright and banded with minor pyrite and amber.
D189023	--do--	---------------do---------------	48.08 - 49.94	Coal, with carb shale and minor pyrite and amber.
D189024	--do--	---------------do---------------	50.52 - 51.87	Coal, bright and banded with minor pyrite and amber.

Tableβ-2.--Proximate and ultimate analyses, heat content, forms-of-sulfur, free-swelling-index and ash fusion temperature determinations for 13 coal samples from Henry Mountain field, Garfield County, Utah.

[All analyses except Kcal/kg, free-swelling-index and ash fusion temperatures in percent. For each sample number, the analyses are reported three ways; first, as received, second, moisture free, and third, moisture and ash free. All analyses by Coal Analysis Section, U.S. Bureau of Mines, Pittsburgh, Pa. °C = (°F-32) 5/9; Kcal/kg = 0.556 Btu/lb.]

Sample number	Proximate Analysis				Ultimate Analysis					
	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Kcal/kg
D189013	13.0	35.0	37.7	14.3	5.5	55.2	1.1	23.2	0.7	5,370
	---	40.2	43.3	16.4	4.7	63.4	1.3	13.4	.8	6,170
	---	48.1	51.9	---	5.6	75.9	1.5	16.0	1.0	7,390
D189014	12.1	37.1	41.4	9.4	5.7	60.6	1.2	22.7	.4	5,920
	---	42.2	47.1	10.7	5.0	68.9	1.4	13.6	.5	6,740
	---	47.3	52.7	---	5.5	77.2	1.5	15.2	.5	7,540
D189015	12.5	33.6	35.7	18.2	5.3	53.1	1.0	21.8	.7	5,160
	---	38.4	40.8	20.8	4.5	60.7	1.1	12.2	.8	5,900
	---	48.5	51.5	---	5.6	76.6	1.4	15.4	1.0	7,450
D189016	12.7	32.2	32.0	23.1	5.2	47.4	1.0	20.1	3.2	4,730
	---	36.9	36.7	26.5	4.3	54.3	1.1	10.1	3.7	5,420
	---	50.2	49.8	---	5.9	73.8	1.6	13.7	5.0	7,370
D189017	12.5	34.6	39.3	13.6	5.5	56.9	1.1	22.5	.5	5,550
	---	39.5	44.9	15.5	4.7	65.0	1.3	13.0	.6	6,340
	---	46.8	53.2	---	5.6	77.0	1.5	15.4	.7	7,510
D189018	13.7	36.5	42.7	7.1	5.8	60.8	1.2	24.6	.6	5,890
	---	42.3	49.5	8.2	5.0	70.5	1.4	14.4	.7	6,830
	---	46.1	53.9	---	5.4	76.8	1.5	15.7	.8	7,440
D189012	11.6	35.4	36.3	16.7	5.4	53.9	1.1	20.2	2.8	5,340
	---	40.0	41.1	18.9	4.7	61.0	1.2	11.2	3.2	6,040
	---	49.4	50.6	---	5.7	75.2	1.5	13.8	3.9	7,450
D189019	11.5	35.3	40.3	12.9	5.4	58.1	1.0	21.8	.8	5,620
	---	39.9	45.5	14.6	4.7	65.6	1.1	13.1	.9	6,340
	---	46.7	53.3	---	5.5	76.9	1.3	15.3	1.1	7,430
D189020	11.0	35.4	37.0	16.6	5.4	54.2	1.0	22.3	.4	5,250
	---	39.8	41.6	18.7	4.7	60.9	1.1	14.1	.4	5,890
	---	48.9	51.1	---	5.8	74.9	1.4	17.3	.6	7,240
D189021	9.5	32.7	33.3	24.5	4.7	48.5	.9	19.4	2.0	4,730
	---	36.1	36.8	27.1	4.0	53.6	1.0	12.1	2.2	5,230
	---	49.5	50.5	---	5.5	73.5	1.4	16.6	3.0	7,160
D189022	11.6	36.6	42.7	9.1	5.6	60.8	1.2	22.8	.6	5,900
	---	41.4	48.3	10.3	4.9	68.8	1.4	14.1	.7	6,680
	---	46.2	53.8	---	5.4	76.7	1.5	15.7	.8	7,440
D189023	10.3	36.0	36.3	17.4	5.3	54.0	1.0	21.5	.7	5,220
	---	40.1	40.5	19.4	4.6	60.2	1.1	13.8	.8	5,820
	---	49.8	50.2	---	5.7	74.7	1.4	17.1	1.0	7,220

Table B-3--Proximate and ultimate analyses, heat content, forms-of-sulfur, free-swelling-index and ash fusion temperature determinations for 13 coal samples from Henry Mountain field, Garfield County, Utah.--Continued

Sample number	Air-dried loss	Forms of sulfur			Free swelling	Ash fusion temperature C`		
		Sulfate	Pyritic	Organic		Initial deform.	soften.	fluid
D189013	2.0	0.01	0.33	0.34	0.0	1,235	1,285	1,345
	---	.01	.38	.39				
	---	.01	.45	.47				
D189014	1.5	.01	.20	.18	.0	1,270	1,320	1,375
	---	.01	.23	.20				
	---	.01	.25	.23				
D189015	1.9	.01	.25	.42	.0	1,320	1,375	1,430
	---	.01	.29	.48				
	---	.01	.36	.61				
D189016	2.5	.02	2.10	1.09	.0	1,125	1,175	1,230
	---	.02	2.41	1.25				
	---	.03	3.27	1.70				
D189017	2.0	.01	.20	.26	.0	1,265	1,325	1,380
	---	.01	.23	.30				
	---	.01	.27	.35				
D189018	2.1	.01	.28	.31	.0	1,125	1,180	1,230
	---	.01	.32	.36				
	---	.01	.35	.39				
D189012	1.3	.02	1.86	.89	.0	1,150	1,205	1,255
	---	.02	2.10	1.01				
	---	.03	2.59	1.24				
D189019	1.0	.01	.55	.26	.0	1,200	1,265	1,380
	---	.01	.62	.29				
	---	.01	.73	.34				
D189020	.5	.01	.20	.20	.0	1,540	1,540	1,540
	---	.01	.22	.22				
	---	.01	.28	.28				
D189021	.4	.02	1.06	.97	.0	1,375	1,430	1,485
	---	.02	1.17	1.07				
	---	.03	1.61	1.47				
D189022	.5	.01	.29	.29	.0	1,205	1,255	1,315
	---	.01	.33	.33				
	---	.01	.37	.37				
D189023	.7	.01	.31	.41	.0	1,380	1,435	1,490
	---	.01	.35	.46				
	---	.01	.43	.57				

Table B-4--Proximate and ultimate analyses, heat content, forms-of-sulfur, free-swelling-index and ash fusion temperature determinations for 13 coal samples from Henry Mountain field, Garfield County, Utah.--Continued

Sample number	Proximate Analysis				Ultimate Analysis					
	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Kcal/kg
D189024	10.9	38.2	42.4	8.5	5.8	61.0	1.1	22.6	1.0	5,990
	---	42.9	47.6	9.5	5.2	68.5	1.2	14.5	1.1	6,730
	---	47.4	52.6	---	5.7	75.7	1.4	16.0	1.2	7,440

Sample number	Air-dried loss	Forms of sulfur			Free swelling	Ash fusion temperature C`		
		Sulfate	Pyritic	Organic		Initial deform.	soften.	fluid
D189024	0.6	0.01	0.26	0.77	0.0	1,320	1,375	1,425
	---	.01	.29	.86				
	---	.01	.32	.96				

Table B-5--Major and minor oxide and trace element composition of the laboratory ash of 13 coal samples from Henry Mountain field, Garfield County, Utah.

[Values in percent or parts-per-million. Coal ashed at 525°C. L means less than the value shown; N, not detected; S after element title indicated determinations by semiquantative emissionspectrography; to be identified with geometric brackets whose boundaries are part of the ascending series 0.12, 0.18, 0.26, 0.38, 0.56, 0.83, 1.2, etc., but reported as mid-points of the brackets, 0.1, 0.15, 0.2, 0.3, 0.5, 0.7, 1.0, etc. Precision of the spectrographic data is plus-or-minus one bracket at 68 percent or plus-or-minus two brackets at 95 percent confidence level.]

Sample number	Ash (percent)	SiO2 (percent)	Al2O3 (percent)	CaO (percent)	MgO (percent)	Na2O (percent)	K2O (percent)	Fe2O3 (percent)	TiO2 (percent)	P2O5 (percent)	Sample number
D189013	14.5	58	17	10	1.96	0.13	0.73	3.3	0.87	1.0L	D189013
D189014	10.8	65	7.8	12	2.31	.24	.54	3.1	1.2	1.0L	D189014
D189015	19.7	61	17	6.2	1.58	.54	1.2	2.5	1.0	1.0L	D189015
D189016	19.6	50	12	6.5	1.49	.92	1.2	17	.70	1.0L	D189016
D189017	15.6	65	14	8.4	1.76	.51	.62	2.5	1.0	1.0L	D189017
D189018	8.3	30	11	29	2.80	1.30	.48	4.4	.60	1.0L	D189018
D189012	18.3	46	18	7.5	1.36	.40	.74	15	1.1	1.0L	D189012
D189019	13.0	60	12	8.9	2.00	.75	.44	5.8	1.0	1.0L	D189019
D189020	19.6	54	27	9.0	1.03	.95	1.2	1.0	.79	1.0L	D189020
D189021	10.2	57	24	6.0	1.18	.28	1.1	6.3	1.0	1.0L	D189021
D189022	9.8	53	14	13	2.09	2.75	.43	3.5	.88	1.0L	D189022
D189023	20.0	51	23	14	1.27	1.09	.66	1.9	.88	1.0L	D189023
D189024	9.1	38	22	16	2.53	1.62	.31	4.9	1.2	1.0L	D189024

Sample number	SO3 (percent)	B-S (ppm)	Ba-S (ppm)	Be-S (ppm)	Cd (ppm)	Cu (ppm)	Ga-S (ppm)	Ge-S (ppm)	La-S (ppm)	Li (ppm)	Sample number
D189013	6.9	1,000	150	15	1.0L	113	30	20	70	155	D189013
D189014	7.9	1 000	2,000	20	1.0L	68	30	30	N	55	D189014
D189015	4.3	700	1,000	7	1.0L	100	30	N	70	147	D189015
D189016	8.5	700	500	10	1.0L	32	20	20	70	52	D189016
D189017	6.1	1,000	1,000	7	1.0L	83	30	N	N	116	D189017
D189018	12	2,000	1,000	3	1.0L	60	30	N	70	89	D189018
D189012	8.0	700	500	3	1.0L	38	30	N	N	73	D189012
D189019	9.9	1 500	1,500	7	1.0L	100	30	N	N	114	D189019
D189020	3.9	1 500	700	15	1.0L	45	70	N	70	87	D189020
D189021	4.8	700	300	N	1.0L	47	30	N	N	215	D189021
D189022	12	3,000	300	5	1.0L	111	30	N	N	113	D189022
D189023	5.7	1,500	300	3	1.0L	50	30	N	N	97	D189023
D189024	15	2,000	1,500	3	1.0L	65	50	N	70	200	D189024

Table B-6--Major and minor oxide and trace element composition of the laboratory ash of 13 coal samples from Henry Mountain field, Garfield County, Utah.--Continued

Sample number	Mn (ppm)	Mo-S (ppm)	Nb-S (ppm)	Ni-S (ppm)	Pb (ppm)	Sc-S (ppm)	Sr-S (ppm)	V-S (ppm)	Y-S (ppm)	Yb-S (ppm)	Sample number
D189013	110	7	30	30	45	30	300	150	150	10	D189013
D189014	180	N	30	50	50	15	500	70	100	7	D189014
D189015	130	5	20	30	40	15	300	150	70	7	D189015
D189016	350	15	20	30	25L	15	700	70	100	10	D189016
D189017	100	N	20	20	25L	15	700	70	70	7	D189017
D189018	610	10	20	50	50	30	1,000	200	100	7	D189018
D189012	165	N	30	15	45	10	700	70	70	5	D189012
D189019	140	10	20	30	25	10	300	70	70	7	D189019
D189020	65	7	30	10	60	7	500	70	70	7	D189020
D189021	95	7	20	15	25	15	300	100	50	5	D189021
D189022	90	10	20	20	40	15	700	70	70	5	D189022
D189023	205	N	20	15	40	7	300	70	70	5	D189023
D189024	170	7	20	15	35	7	700	70	70	3	D189024

Sample number	Zn (ppm)	Zr-S (ppm)
D189013	76	150
D189014	129	200
D189015	78	150
D189016	99	150
D189017	59	200
D189018	70	100
D189012	51	200
D189019	53	300
D189020	77	300
D189021	66	150
D189022	148	150
D189023	83	150
D189024	33	200

Table B-7.--Content of nine trace elements in 13 coal samples from Henry Mountain field, Garfield County, Utah.

[Analyses on air-dried (32°C) coal. Values in parts-per-million (ppm). L, less than the value shown, B, not determined.]

Sample number	As (ppm)	Co (ppm)	Cr (ppm)	F (ppm)	Hg (ppm)	Sb (ppm)	Se (ppm)	Th (ppm)	U (ppm)	Sample number
D189013	1.9	2.4	11	50	0.04	1.3	1.8	2.5	3.4	D189013
D189014	.5	4.0	7.2	20L	.03	.6	1.6	1.3	2.0	D189014
D189015	1.5	3.1	17	85	.05	1.1	2.2	3.4	2.6	D189015
D189016	9.4	2.5	11	80	.27	1.1	1.3	3.1	9.4	D189016
D189017	.5	1.2	9.0	55	.03	.3	2.0	2.1	2.5	D189017
D189018	.7	1.5	11	20L	.02	.3	1.5	1.9	1.1	D189018
D189012	1.0	.8	8.0	35	.16	.3	1.9	5.0	2.3	D189012
D189019	.8	1.7	5.5	20	.07	.4	1.9	1.7	1.4	D189019
D189020	.6	1.4	3.9	50	.02	.7	1.1	8.3	4.5	D189020
D189021	2.0	2.1	21	150	.10	.4	2.0	8.1	4.8	D189021
D189022	1.2	.8	B	20L	.05	.2	.6	1.3	1.2	D189022
D189023	1.2	.6	1.4	50	.08	.1	.6	.9	4.4	D189023
D189024	.7	.6	3.4	20L	.09	.2	1.4	2.7	1.5	D189024

Table B-8--Major, minor, and trace element composition of 13 coal samples from Henry Mountain field, Garfield County, Utah.

[Values in percent or parts-per-million. As, Co, Cr, F, Hg, Sb, Se, Th, U, values are from direct determinations on air dried (32°C) coal; all other values calculated from analyses of ash. S means analysis by emissionspectrography; L,less than the value shown; N, not detected; B, not determined.]

Sample number	Si (percent)	Al (percent)	Ca (percent)	Mg (percent)	Na (percent)	K (percent)	Fe (percent)	Ti (percent)	As (ppm)	B-S (ppm)	Sample number
D189013	3.9	1.3	1.0	0.17	0.014	0.088	0.33	0.076	1.9	150	D189013
D189014	3.3	.45	.93	.15	.019	.049	.23	.078	.5	100	D189014
D189015	5.6	1.8	.87	.19	.079	.20	.34	.12	1.5	150	D189015
D189016	4.6	1.2	.91	.18	.13	.20	2.3	.082	9.4	150	D189016
D189017	4.7	1.2	.94	.17	.059	.081	.27	.093	.5	150	D189017
D189018	1.2	.48	1.7	.14	.080	.033	.26	.030	.7	150	D189018
D189012	3.9	1.7	.98	.15	.054	.11	1.9	.12	1.0	150	D189012
D189019	3.6	.83	.83	.16	.072	.048	.53	.078	.8	200	D189019
D189020	4.9	2.8	1.3	.12	.14	.20	.14	.093	.6	300	D189020
D189021	2.7	1.3	.44	.072	.021	.093	.45	.061	2.0	70	D189021
D189022	2.4	.73	.91	.12	.20	.035	.24	.052	1.2	300	D189022
D189023	4.8	2.4	2.0	.15	.16	.11	.27	.11	1.2	300	D189023
D189024	1.6	1.1	1.0	.14	.11	.023	.31	.065	.7	200	D189024

Sample number	Ba-S (ppm)	Be-S (ppm)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	F (ppm)	Ga-S (ppm)	Ge-S (ppm)	Hg (ppm)	Sample number
D189013	20	2	0.14L	2.4	11	16	50	5	3	0.04	D189013
D189014	200	2	.11L	4.0	7.2	7.3	20L	3	3	.03	D189014
D189015	200	1.5	.20L	3.1	17	20	85	7	N	.05	D189015
D189016	100	2	.20L	2.5	11	6.3	80	5	5	.27	D189016
D189017	150	1	.16L	1.2	9.0	13	55	5	N	.03	D189017
D189018	100	.2	.08L	1.5	11	5.0	20L	2	N	.02	D189018
D189012	100	.5	.18L	.8	8.0	7.0	35	5	N	.16	D189012
D189019	200	1	.13L	1.7	5.5	13	20	5	N	.07	D189019
D189020	150	3	.20L	1.4	3.9	8.8	50	15	N	.02	D189020
D189021	30	N	.10L	2.1	21	4.8	150	3	N	.10	D189021
D189022	30	.5	.10L	.8	B	11	20L	3	N	.05	D189022
D189023	70	.7	.20L	.6	1.4	10	50	7	N	.08	D189023
D189024	150	.3	.09L	.6	3.4	5.9	20L	5	N	.09	D189024

Table B-9.--Major, minor, and trace element composition of 13 coal samples from Henry Mountain field, Garfield County, Utah.
--Continued

Sample number	La-S (ppm)	Li (ppm)	Mn (ppm)	Mo-S (ppm)	Nb-S (ppm)	Ni-S (ppm)	P (ppm)	Pb (ppm)	Sb (ppm)	Sc-S (ppm)	Sample number
D189013	10	22	16	1	5	5	630L	6.5	1.3	5	D189013
D189014	N	5.9	19	N	3	5	470L	5.4	.6	1.5	D189014
D189015	15	29	26	1	5	7	860L	7.9	1.1	3	D189015
D189016	15	10	69	3	5	7	860L	4.9L	1.1	3	D189016
D189017	N	18	16	N	3	3	680L	3.9L	.3	2	D189017
D189018	7	7.4	51	1	1.5	5	360L	4.1	.3	2	D189018
D189012	N	13	30	N	5	3	800L	8.2	.3	2	D189012
D189019	N	15	18	1.5	2	5	570L	3.3	.4	1.5	D189019
D189020	15	17	13	1.5	7	2	860L	12	.7	1.5	D189020
D189021	N	22	9.7	.7	2	1.5	450L	2.6	.4	1.5	D189021
D189022	N	11	8.8	1	2	2	430L	3.9	.2	1.5	D189022
D189023	N	19	41	N	5	3	870L	8.0	.1	1.5	D189023
D189024	7	18	15	.7	2	1.5	400L	3.2	.2	.7	D189024

Sample number	Se (ppm)	Sr-S (ppm)	Th (ppm)	U (ppm)	V-S (ppm)	Y-S (ppm)	Yb-S (ppm)	Zn (ppm)	Zr-S (ppm)	Sample number
D189013	1.8	50	2.5	3.4	20	20	1.5	11	20	D189013
D189014	1.6	50	1.3	2.0	7	10	.7	14	20	D189014
D189015	2.2	70	3.4	2.6	30	15	1.5	15	30	D189015
D189016	1.3	150	3.1	9.4	15	20	2	19	30	D189016
D189017	2.0	100	2.1	2.5	10	10	1	9.2	30	D189017
D189018	1.5	100	1.9	1.1	15	10	.7	5.8	10	D189018
D189012	1.9	150	5.0	2.3	15	15	1	9.3	30	D189012
D189019	1.9	50	1.7	1.4	10	10	1	6.9	50	D189019
D189020	1.1	100	8.3	4.5	15	15	1.5	15	70	D189020
D189021	2.0	30	8.1	4.8	10	5	.5	6.7	15	D189021
D189022	.6	70	1.3	1.2	7	7	.5	15	15	D189022
D189023	.6	70	.9	4.4	15	15	1	17	30	D189023
D189024	1.4	70	2.7	1.5	7	7	.3	3.0	20	D189024

Appendix C.

Soil descriptions of units mapped by the Soil Conservation Service in their 1977 soil survey of the Henry Mountains coal resource area. Terms used in the following descriptions are defined in the report.

BaD Ba-Rock outcrop complex, 4 to 15 percent slopes

This complex occurs on mesa tops in the Tarantula Mesa area. It consists of about 40 percent Ba fine sandy loam, 4 to 15 percent slopes, and about 35 percent rock outcrop. Included in this complex in mapping are small areas of Ca loamy fine sandy, 2 to 8 percent slopes; small areas of Aa very fine sandy loam, 2 to 4 percent slopes, and small areas of Ga silty clay, 2 to 15 percent slopes. This soil and rock outcrop occur in an intermixed pattern on undulating mesa tops, usually near the edges and very steep breaks.

The Ba fine sandy loam, 4 to 15 percent slopes, is a shallow, somehwat excessively drained soil that occurs on Tarantula and Wildcat Mesas. It formed in residuum primarily from sandstone. Shale underlies this soil in places. Natural vegetation is juniper, Mormon tea, fourwing saltbush, owl clover, galleta, bluegrama and Indian ricegrass. Elevations range from 5,000 to 6,400 feet. Average annual precipitation is 8 to 12 inches. Mean annual air temperature is 48^{0} to 52^{0} F., and the frost free period is 120 to 150 days.

In a typical profile the surface layer is light yellowish brown, fine sandy loam about 6 inches thick. The underlaying layer is pale brown, fine sandy loam about 6 inches thick. It is underlain by sandstone bedrock.

Permeability is moderately rapid. Runoff is medium, and the erosion hazard is severe. The available water capacity is 1.0 to 2.5 inches above the bedrock.

This soil is used for rangeland and wildlife.

A representative profile of Ba fine sandy loam, 4 to 15 percent slopes in section 30, T 33 S R 9 E) in a rangeland area follows.

A1--0 to 6 inches; light yellowish brown (10YR 6/4) fine sandy loam, yellowish brown (10YR 5/4) moist; moderate, fine granular structure; soft, very friable, slightly sticky, nonplastic; few fine roots; many very fine and few fine pores; moderately calcareous, lime is disseminated; moderately alkaline (pH 8.4); clear smooth boundary.

C--6 to 12 inches; pale brown (10YR 6/3) fine sandy loam, brown to dark brown (10YR 4/3) moist; weak, medium subangular blocky structure; soft, very friable, slightly sticky, slightly plastic; common fine and few medium roots; common fine pores; 5 percent gravel; moderately calcareous, lime is disseminated; moderately alkaline (pH 8.3); abrupt, smooth boundary.

R--12 inches; sandstone bedrock

Commonly a desert pavement of gravel size fragments covers 20 to 30 percent of the surface.

The A1 horizon has hue of 7.5YR or 10YR, value of 5 or 6 dry, 4 or 5 moist. The texture is dominantly fine sandy loam and has up to 10 percent fine gravel. Structure is weak to moderate fine granular, and commonly the upper 1/2 inch is weak moderately thick platy. Thickness is 3 to 6 inches. The C horizon has hue of 7.5YR or 10YR, value of 6 or 6 dry, 4 through 6 moist and chroma of 3 or 4. Texture is fine sandy loam or light loam. Depth to bedrock is 6 to 20 inches.

This soil is in capability unit VIIe-R, nonirrigated; Woodland Suitability group 5d6.

The Rock outcrop in this mapping unit is mainly bare exposure of sandstone.

(b) BdF Rock outcrop-Ba complex, excessively rocky

This complex occurs on steep hogbacks on the Wildcat Mesa. It consists of about 70 percent rock outcrop, and about 25 percent Ba stony sandy loam, 15 to 40 percent slopes. Included in this mapping unit are small areas of Ba fine sandy loam, 4 to 15 percent slopes.

The soils in this mapping unit occur in small depression areas usually surrounded by bedrock or at the base of short slopes within the delineation.

The Ba soil is similar to Ba fine sandy loam, 4 to 15 percent slopes, except the surface layer is stony, and the texture is sandy loam. Slopes range from 15 to 40 percent. Depth to bedrock is 6 to 12 inches.

This complex is in capability unit VIIe-R, nonirrigated; the Ba soil is in Woodland Suitability group 5d6.

(c) BB Badland

This miscellaneous land area consists of very steep slopes and rolling hills of nearly barren marine shale. Erosion is active and sediment production is very high during periods of runoff from intense thunderstorms.

This badland is in capability unit VIIIs-3.

(d) RB Badland-Rock outcrop complex

This complex occurs on very steep breaks from high mesa to lower lying terraces and drainage ways. It consists of about 50 percent badland and 35 percent rock outcrop. The rock outcrop dominantly occurs on the upper part of the unit, but in places, is at intermediate levels. It is most usually nearly vertical escarpments. The adland member occurs as very steep slopes of marine shale. Geologic erosion is active and sediment production is high from these areas.

Included in this unit in mapping are small areas of Da extremely stony clay loam, 15 to 50 percent slopes; and small areas of Ga gravelly silty clay, 30 to 60 percent slopes.

This complex is in capability unit VIIIs-3.

(e) FaB Fa loamy fine sand, 2 to 4 percent slopes

This is a deep, well-drained soil that occurs on old outwash fans mainly in the north part of the survey area. It has formed in alluvium from sandstone and shale. Natural vegetation is galleta, Indian ricegrass, blue grama, Mormon tea, shadscale, ragweed and snakeweed. Elevations range from 5,200 to 6,200 feet. Average annual precipitation is 8 to 10 inches. Mean annual air temperature is 48^{o} to 52^{o} F., and the frost-free period is 120 to 150 days.

In a typical profile the surface layer strong brown, loamy fine sand about 5 inches thick. The underlaying layers are brown, very fine sandy loam to depths of 42 inches, or more and is underlain by sandstone bedrock.

Permeability is moderately rapid. Runoff is slow and the erosion hazard is moderate. The available water capacity is 6 to 8 inches to bedrock or 5 feet.

This soil is used for rangeland and wildlife.

Included with this soil in mapping are small areas of Ba fine sandy loam, 4 to 15 percent slopes; small areas of a deep, loamy fine sand soil; and small areas of this soil on slopes of 4 to 8 percent.

A representative profile of Fa loamy fine sand, 2 to 4 percent slopes, in section 3, (T 31 S R 8 E) in a rangeland area follows.

A1--0 to 5 inches; strong brown (7.5YR 5/6) loamy fine sand, brown to dark brown (7.5YR 4/4) moist; weak, medium granular structure; soft, very friable, nonsticky, nonplastic; many very fine and fine roots; common fine and few medium pores; slightly calcareous, lime is disseminated; moderately alkaline (pH 8.4); clear smooth boundary.

C1--5 to 21 inches; brown (7.5YR 5/4) very fine sandy loam, brown to dark brown (7.5YR 4/4) moist; weak, medium subangular blocky structure; soft very friable, nonsticky, nonplastic; few, very fine and fine roots; few, fine and medium pores; slightly calcareous, lime is disseminated; moderately alkaline (pH 8.3); clear smooth boundary.

C2--21 to 35 inches; brown (7.5YR 5/4) very fine sandy loam, brown to dark brown (7.5YR 4/4) when moist; slightly hard, very friable, nonsticky, nonplastic; few fine and medium roots; few, fine and medium pores; moderately calcareous, lime is disseminated and some soft modules; moderately alkaline (pH 8.4); clear smooth boundary.

C3--35 to 42 inches; brown (7.5YR 5/4) very fine sandy loam, brown (7.5YR 5/4) moist; massive; soft, very friable, nonsticky, nonplastic; few fine roots; common very fine, few fine pores; moderately calcareous, lime is disseminated; strongly alkaline (pH 8.4); gradual smooth boundary.

R--42 inches; soft sandstone bedrock

The A1 horizon has hue of 7.5YR or 10YR, value 5 or 6 dry, 4 moist, and chroma of 3 through 6. Texture is dominantly loamy fine sand, but ranges to fine sandy loam in places. Structure is weak, fine to medium granular. The A1 horizon is 3 to 5 inches thick. The C horizon has hue of 7.5YR or 10YR, value 5 or 6 dry, 4 or 5 moist and chroma of 2 through 4. Texture is very fine sandy loam and is commonly stratified with loamy fine sand. Depth to bedrock is 40 to more than 60 inches.

This soil is in capability unit VIe-R, nonirrigated; Semidesert Loam (summer precipitation) range site.

(f) GaD Ga silty clay, 2 to 15 percent slopes

This is a shallow well-drained soil that occurs on old mesa remnants and steep uplands. It formed in residuum from marine shale. Natural vegetation is shadscale, fourwing saltbush, snakeweed, galleta, and Indian ricegrass. Elevations range from 5,000 to 6,000 feet. Average annual precipitation is 8 to 10 inches. Mean annual air temperature is 48^0 to 52^0 F., and the frost-free period is 120 to 150 days.

In a typical profile the surface layer is dark drayish brown, silty clay about 3 inches thick. The underlaying layer is grayish brown silty clay about 9 inches thick over weathered marine shale bedrock.

Permeability is slow. Runoff is rapid and the erosion hazard is severe. The available water capacity is 1 to 2 inches to bedrock.

This soil is used for rangeland and wildlife.

Included with this soil in mapping are small areas of Ba stony sandy loam, 15 to 40 percent slopes, Ga gravelly silty clay 30 to 60 percent slopes, small areas of badland and small areas of rock outcrop.

A representative profile of Ga silty clay, 2 to 15 percent slopes, in section 15, (T 31 S R 8 E) in a rangeland area follows.

A1--0 to 3 inches; dark grayish brown (2.5YR 4/2) silty clay, dark grayish brown (2.5YR 4/2) moist; weak, fine and medium granular structure; hard, very firm, very sticky, very plastic, few, fine roots; common, very fine and fine pores; noncalcareous; mildly alkaline (pH 7.8); abrupt, smooth boundary.

C1--3 to 12 inches; grayish brown (2.5YR 5/2) light silty clay, dark grayish brown (2.5YR 4/2) moist; massive; very hard, very firm, very sticky, very plastic; few, fine roots; few, very fine and fine pores; noncalcareous; moderately alkaline (pH 8.0); gradual smooth boundary.

C2r--12 inches; weathered shale bedrock.

The A1 horizon hue is 2.5Y or 10YR, value 4 or 5 dry, 4 moist and chroma of 2 through 4. Texture is silty clay, marginal to silty clay loam in places, having up to 30 percent gravel and 5 percent cobble in some places. Structure is weak to moderate, fine to medium granular. The C horizon is 2.5Y or 10YR, value of 4 though 6 dry, 3 through 5 moist and chroma of 2 through 4. Texture is heavy silty clay loam or silty clay. Depth to weathering marine shale is 10 to 16 inches.

This soil is in Capability unit is VIIe-R, nonirrigated; Desert Shallow Shale range site.

(g) GaG Ga gravelly silty clay, 30 to 60 percent slopes

This soil is similar to Ga silty clay, 2 to 15 percent slopes, except the surface contains 20 to 35 percent gravel and slopes are 30 to 60 percent.

Included with this soil in mapping unit are small areas of Ha fine sandy loam, 4 to 8 percent slopes; small areas of Da extremely stony clay loam, 15 to 50 percent slopes; small areas of Badland and Rock outcrop.

This soil is in Capability unit VIIe-R, nonirrigated; Desert Shallow Shale range site.

(h) HaB Ha fine sandy loam, 2 to 4 percent slopes

This is a deep, well-drained soil that occurs in alluvial valleys and outwash fans. It formed in alluvium from sandstone and shale. Natural vegetation is juniper, shadscale, snakeweed, Russian thistle, sunflower and galleta. Elevations range from 5,200 to 5,600 feet. Average annual precipitation is 8 to 10 inches. Mean annual air temperature is 48° to 52°F., and the frost-free period is 120 to 150 days.

In a typical profile the surface layer is pale brown, fine sandy loam about 5 inches thick. The underlying layer is pale brown fine sandy loam to a depth of 60 inches or more.

Permeability is moderately rapid. Runoff is slow and the erosion hazard is moderate. The available water capacity is 6 to 8 inches to a depth of 5 feet.

This soil is used for rangeland and wildlife.

Included with this soil in mapping are small areas of Ga gravelly silty clay, 30 to 60 percent slopes; small areas of Ja silty loam, 0 to 2 percent slopes; and Badland.

A representative profile of Ha fine sandy loam, 2 to 4 percent slopes in section 22, (T 32 S R 8 E) in a rangeland area follows:

A1--0 to 5 inches; pale brown (10YR 6/3) fine sandy loam, brown (10YR 5/3) moist; weak, medium subangular blocky structure that parts to weak, fine granular; loose, very friable, nonsticky, nonplastic; common fine and few medium roots; common fine and few medium pores; moderately calcareous, lime is disseminated; moderately alkaline (pH 8.2); clear smooth boundary.

C1--5 to 19 inches; pale brown (10YR 6/3) fine sandy loam, brown (10YR 5/3) moist; weak, medium subangular blocky structure; loose, very friable, nonsticky, nonplastic; few, fine medium and coarse roots; common fine and few medium pores; moderately calcareous, lime is disseminated; strongly alkaline (pH 8.5); gradual smooth boundary.

C2--19 to 30 inches; pale brown (10YR 6/3) fine sandy loam, brown (10YR 5/3) moist; weak, medium subangular blocky structure; loose, very friable, nonsticky, nonplastic; few fine roots; common very fine and fine, few medium pores; moderately calcareous, lime is disseminated; strongly alkalaine (pH 8.8); gradual smooth boundary.

C3-30 to 60 inches; pale brown (10YR 6/3) fine sandy loam, brown (10YR 5/3) moist; single grain structure; loose, very friable, nonsticky, nonplastic; moderately calcareous, lime is disseminated; strongly alkaline (pH 9.0).

The A1 horizon has hue of 10YR and 2.5Y, value of 6 dry, 4 or 5 moist and chroma of 3 or 4. Texture is dominantly fine sandy loam, but ranges to light loam. In places the A1 horizon contains 10 to 15 percent fine gravel. The C horizon has hue of 10YR or 2.5Y, value of 5 or 6 dry, 4 or 5 moist and chroma of 3 or 4. Texture is fine sandy loam, loam and loamy fine sand and is stratified in most profiles. Gravel content is 0 to 20 percent and thin layers (less than 2 inches thick) contain 40 to 60 percent fine gravel.

This soil is in capability unit VIr-R, nonirrigated; Semidesert Loam (Summer Precipitation) range site.

(i) HaC Ha fine sandy loam, 4 to 8 percent slopes

This deep, well drained soil occurs in alluvial valleys and outwash fans. It formed in alluvium from sandstone and shale. Natural vegetation is juniper, shadscale, snakeweed, Russian thistle, sunflower and galleta. Elevations range from 5,200 to 5,600 feet. Average annual precipitation is 8 to 10 inches. Mean annual air temperature is 48^{o} to 52^{o} F., and the frost-free period is 120 to 150 days.

In a typical profile the surface layer is pale brown, fine sandy loam about 5 inches thick. The underlying layer is pale brown fine sandy loam to a depth of 60 inches or more.

Permeability is moderately rapid. Runoff is slow and the erosion hazard is moderate. The available water capacity is 6 to 8 inches to a depth of 5 feet.

This soil is used for rangeland and wildlife.

Included with this soil in mapping are small areas of Ga gravelly silty clay, 30 to 60 percent slopes; small areas of Ja silty loam, 0 to 2 percent slopes; and badland.

This soil has a profile similar to that described for the Ha fine sandy loam, 2 to 4 percent slope, except slopes are 4 to 8 percent.

This soil is in capability unit VIe-R, nonirrigated; Semidesert Loam (Summer Precipitation) range site.

(j) JaA Ja silt loam, 0 to 2 percent slopes

This is a deep, well-drained soil that occurs on alluvial valleys. These valleys have many shallow gullies that originate on adjacent badland areas. This soil formed in alluvium from sandstone and shale. Natural vegetation is Russian thistle, sunflower and bottle-stopper. Elevations range from 5,000 to 5,600 feet. Average annual precipitation is 8 to 10 inches. Mean annual air temperature is 48^{0} to 52^{0} F., and the frost-free period is 120 to 150 days.

In a typical profile the surface layer is grayish brown, silt loam about 9 inches thick. The underlying layer is grayish brown loam or silt loam about 25 inches thick. The next underlying layer is grayish brown silt loam to 60 inches or more.

Permeability is moderate. Runoff is slow, and the erosion hazard is moderate. The available water capacity is 6.0 to 8.0 inches to a depth of 5 feet.

This soil is used for rangeland and wildlife.

Included with this soil in mapping are small areas of Ga silty clay, 2 to 15 percent slopes; small areas of Ha fine sandy loam, 2 to 4 percent slopes; and small areas of badland.

A representative profile of Ja silt loam, 0 to 2 percent slopes in section 34, (T 31 S R 8 E) in a rangeland area follows:

A1--0 to 9 inches; grayish brown (2.5Y 5/2) silt loam, dark grayish brown (2.5Y 4/2) when moist; weak, thick platy structure that parts to weak, medium subangular blocky; slightly hard, friable, slightly sticky, slightly plastic; few fine roots; common very fine and fine pores; moderately calcareous, lime is disseminated; strongly alkaline (pH 8.6) abrupt, smooth boundary.

C1--9 to 16 inches; grayish brown (2.5Y 5/2) loam, dark grayish brown (2.5Y 4/2) moist; weak, medium subangular blocky structure; soft, friable, slightly sticky, slightly plastic; few, fine roots; few, very fine and fine pores; moderately calcareous, lime is disseminated; strongly alkaline (pH 8.5); clear smooth boundary.

C2--16 to 21 inches; grayish brown (2.5Y 5/2) loam, dark grayish brown (2.5Y 4/2) moist; weak, medium subangular blocky structure; slightly hard, friable, slightly sticky, slightly plastic; few, fine roots; few fine and medium pores; moderately calcareous, lime is disseminated; moderately alkaline (pH 8.3); clear smooth boundary.

C3--21 to 34 inches; grayish brown (2.5Y 5/2) silt loam, dark grayish brown (2.5Y 4/2) moist; massive; slightly hard, friable, slightly sticky, slightly plastic; few fine roots; common, very fine and fine pores; moderately calcareous, lime is disseminated; moderately alkaline (pH 8.0); clear smooth boundary.

C4--34 to 72 inches; grayish brown (2.5Y 5/2) silt loam, dark grayish brown (2.5Y 4/2) moist; massive; soft, friable, sticky, slightly plastic; moderately calcareous, lime is disseminated; moderately alkaline (pH 8.3).

(k) MaB Ma very fine sandy loam, 2 to 4 percent slopes

This is a deep, somewhat excessively drained soil that occurs on old alluvial fans. It formed in alluvium from monzonite, andesite and other igneous rocks and sandstone. Natural vegetation is galleta, snakeweed, hopsage and scattered juniper. Elevations range from 5,000 to 6,000 feet. Average annual precipitation is 8 to 10 inches. Mean annual air temperature is 48^0 to 52^0 F., and the frost-free season is 120 to 150 days.

In a typical profile the surface layer is light brown, very fine sandy loam about 9 inches thick. The subsoil is brown loam about 9 inches thick. The substrating is very pale brown gravelly fine sandy loam about 8 inches thick. This is underlain by very pale brown very cobbly sandy loam to a depth of 5 feet or more.

Permeability is moderately rapid. Runoff is slow and the erosion hazard is moderate. The available water capacity is 5 to 6 inches to a depth of 5 feet.

This soil is used for rangeland and wildlife.

Included with this soil in mapping are small areas of Na fine sandy loam, 2 to 4 percent slopes; and small areas of Ustic Torrifluvents.

A representative profile of Ma very fine sandy loam, 2 to 4 percent slopes in section 17, (T 31 S R 9 E) in a rangeland area follows:

All--0 to 2 inches; light brown (7.7YR 6/4) very fine sandy loam, brown (7.5YR 4/4) moist; weak fine granular structure; soft, very friable, nonsticky, nonplastic; common very fine pores; 10 to 15 percent gravel; slightly calcareous, lime is disseminated; strongly alkaline (pH 8.9); abrupt smooth boundary.

A12--2 to 9 inches; brown (7.5YR 5/4) very fine sandy loam, brown (7.5YR 4/4) moist; weak, fine subangular blocky structure; soft, very friable, nonsticky, nonplastic; common fine roots; common fine and few medium pores; 10 to 15 percent gravel; slightly calcareous, lime is desseminated; strongly alkaline (pH 8.9); clear smooth boundary.

B2--9 to 18 inches; brown (7.5YR 5/4) loam, brown (7.5YR 4/4) moist; moderate, medium angular blocky structure; slightly hard, friable, slightly sticky, slightly plastic; few fine roots; few fine and medium pores; 10 to 15 percent gravel; moderately calcareous, lime is disseminated; strongly alkaline (pH 9.0); gradual smooth boundary.

C1ca--18 to 26 inches; very pale brown (10YR 8/4) gravelly fine sandy loam, very pale brown (10YR 7/4) moist; weak, medium subangular structure; slightly hard, friable, slightly sticky, nonplastic; few, fine roots; few, very fine and fine pores; 15 percent gravel and 5 percent cobble; very strongly calcareous, lime is disseminated; strongly alkaline (pH 9.0); gradual smooth boundary.

C2ca--26 to 60 inches; very pale brown (10YR 7/3) very cobbly sandy loam, pale brown (10YR 6/3) moist; soft, very friable, slightly sticky, nonplastic; few fine roots; 40 percent gravel and 25 percent cobbles; slightly calcareous, lime is disseminated; very strongly alkaline (pH 9.4).

Gravel and cobble on the surface covers about 10 to 15 percent of the area. The A1 and B2 horizons contain 10 to 15 percent gravel and about 5 percent cobbles. The lower C horizon contains 40 to 50 percent gravel and 20 to 35 percent cobble. The Cca horizon is very strongly calcareous.

(1) NaB Na fine sandy loam, 2 to 4 percent slopes

This is a deep, well-drained soil that occurs on nearly level mesa tops. It formed in residuum from fine grained sandstone and igneous rocks. Natural vegetation is galleta, Indian ricegrass, fescue, yellowbrush, globemallow, Mormon tea and scattered juniper. Elevations range from 5,200 to 6,000 feet. Average annual precipitation is 8 to 10 inches. Mean annual air temperature is 48° to 52° F., and the frost-free period is 120 to 150 days.

In a typical profile the surface layer is brown, fine sandy loam about 7 inches thick. The subsoil is light brown, fine sandy loam about 9 inches thick. The substratum is pink loam and gravelly loam to 60 inches or more.

Permeability is moderate. Runoff is slow and the erosion hazard is moderate. The available water capacity is 6 to 7.5 inches to a depth of 5 feet.

This soil is used for rangeland and wildlife.

Included with this soil are small areas of Ca loamy fine sand, 2 to 8 percent slopes; and small areas of Ra very cobbly very fine sandy loam, 15 to 40 percent slopes.

A representative profile of Na fine sandy loam, 2 to 4 percent slopes, in section 20, (T 31 S R 9 E) in a rangeland area follows:

A1--0 to 7 inches; brown (7.5YR 5/4) fine sandy loam, brown (7.5YR 4/4) moist; weak, fine subangular structure, soft, very friable, nonsticky, nonplastic; common fine and few large roots; few fine pores; 3 percent gravel; slightly calcareous, lime is disseminated; strongly alkaline (pH 9.0); abrupt smooth boundary.

B2--7 to 16 inches; light brown (7.5YR 6/4) fine sandy loam, brown (7.5YR 4/4) moist; weak, medium subangular blocky structure; slightly hard, friable, slightly sticky, nonplastic; few fine and medium pores; 3 percent gravel moderately calcareous, lime is disseminated; strongly alkaline (pH 9.0); gradual wavy boundary.

C1ca--16 to 39 inches; pink (7.5YR 8/4) loam, pink (7.5YR 7/4) moist; massive; very hard, friable, slightly sticky, slightly plastic; few fine and large roots; few fine pores; 3 percent gravel; very strongly calcareous, lime is disseminated; very strongly alkaline (pH 9.4); gradual smooth boundary.

C2ca--39 to 60 inches; pink (7.5YR 8/4) gravelly sandy loam, pink (7.5YR 7/4) moist; massive; very hard, friable, nonsticky, nonplastic; few, fine pores; 30 percent gravel; very strongly calcareous, lime is desseminated; strongly alkaline (pH 9.2).

Texture at the A1 horizon is dominantly fine sandy loam, but ranges to very fine sandy loam in places. Also, along the edge of the mesa the surface layer contains 20 to 30 percent cobbles. The Cca horizon is strongly to very strongly calcareous.

This soil is in capability unit is VIe-R, nonirrigated; Semidesert Loam (Summer Precipitation) range site.

(m) PaD Pa gravelly very fine sandy loam, 4 to 15 percent slopes

This is a deep, somewhat excessively drained soil that occurs on dissected outwash fans. It formed in alluvium from sandstone and igneous rocks. Natural vegetation is galleta, fescue, yellowbrush, shadscale and scattered Utah juniper. Elevations range from 4,800 to 5,500 feet. Average annual precipitation is 8 to 10 inches. Mean annual air temperature is 48^0 to 52^0 F., and the frost-free period is 120 to 150 days.

In a typical profile the surface layer is brown, gravelly very fine sandy loam, about 10 inches thick. The underlying layer is very pale brown gravelly loam and very gravelly fine sandy loam to 60 inches or more.

Permeability is moderately rapid. Runoff is medium and the erosion hazard is moderate. The available water capacity is 4 to 6 inches to a depth of 5 feet.

This soil is used for rangeland and wildlife.

Included with this soil in mapping are small areas of Ra very cobbly very fine sandy loam, 15 to 40 percent slopes; small areas of Ha fine sandy loam, 2 to 4 percent slopes; and small areas of Badland.

A representative profile of Pa gravelly very fine sandy loam, 4 to 15 percent slopes in section 18 (T 31 S R 9 R) in a rangeland area follows:

A11--0 to 2 inches; grown (7.5YR 5/4) gravelly very fine sandy loam, brown (7.5YR 4/4) moist; weak fine platy structure that parts to weak fine and medium granular; soft, very friable, nonsticky, slightly plastic; common and medium roots; many fine vesicular pores; 15 percent gravel, 5 percent cobbles; moderately calcareous, lime is disseminated; very strongly alkaline (pH 9.1); abrupt, smooth boundary.

A12--2 to 10 inches; brown (7.5YR 5/4) gravelly very fine sandy loam, brown (7.5YR 5/4) moist; weak, fine subangular blocky structure; soft, very friable, slightly sticky, sligthly plastic; common fine and few medium roots; few very fine and fine pores; 25 percent gravel and 5 percent cobbles; moderately calcareous, lime is disseminated; strongly alkaline (pH 8.9); clear wavy boundary.

C1ca--10 to 26 inches; very pale brown (10YR 7.3) gravelly loam, light yellowish brown (2.5Y 6/4) moist; massive; hard, friable, slightly sticky, slightly plastic; few fine roots; few, very fine pores; 30 percent gravel and 10 percent cobbles; strongly calcareous, lime is disseminated; very strongly alkaline (pH 9.1); clear wavy boundary.

C2--26 to 60 inches; very pale brown (10YR 7/4) very gravelly fine sandy loam, light yellowish brown (10YR 6/4) moist; massive; slightly hard, friable, slightly sticky, slightly plastic; 40 percent gravel and 15 percent cobbles; strongly calcareous, lime is disseminated; very strongly alkaline (pH 9.3).

This soil is in capability unit VIe-R, nonirrigated; Semidesert Gravelly Loam (Summer Precipitation) range site.

(n) RaF Ra very cobbly very fine sandy loam, 15 to 40 percent slopes

This is a deep, well-drained soil that occurs on steep mesa breaks below the mesa tops. It formed in colluvium and residuum from sandstone, shale and igneous rocks. Natural vegetation is galleta, scarlet globemallow, yellowbrush, shadscale, rabbitbrush and juniper. Elevations range from 5,000 to 6,000 feet. Average annual precipitation is 8 to 10 inches. Mean annual air temperature is 48° to 52° F., and the frost-free season is 120 to 150 days.

In a typical profile the surface layer is brown very cobbly very fine sandy loam about 8 inches thick. The underlying layer is light yellowish brown very fine sandy loam about 7 inches thick. The next underlying layer is very pale brown, fine sandy loam over weathered shale bedrock at depth of about 48 inches.

Permeability is moderate. Runoff is rapid and the erosion hazard is severe. The available water capacity is 5 to 7.5 inches to a depth of 5 feet.

This soil is used for rangeland and wildlife.

Included with this soil in mapping are small areas of Da extremely stony clay loam, 15 to 50 percent slopes, and small areas of Pa gravelly very fine sandy loam, 4 to 15 percent slopes.

A representative profile of Ra very cobbly very fine sandy loam, 15 to 40 percent slopes in section 18 (T 31 S R 9 E) in a rangeland area follows:

A1--0 to 8 inches; brown (7.5YR 5/4) very cobbly very fine sandy loam, brown (7.5YR 4/4) moist; weak, fine and medium granular structure; soft, very friable, slightly sticky, slightly plastic; few fine and medium roots; few very fine and fine pores; about 1 percent stone, and 35 percent each of cobble and of gravel occur on the surface; moderately calcareous, lime is disseminated; strongly alkaline (pH 9.0); gradual smooth boundary.

AC--8 to 15 inches; light yellowish brown (10YR 6/4) very fine sandy loam, brown (7.5YR 5/4) moist; weak medium subangular blocky structure; soft, very friable, slightly sticky, slightly plastic; few fine roots; common very fine and few fine pores; moderately calcareous, lime is disseminated; strongly alkaline (pH 8.9) gradual smooth boundary.

C1ca--15 to 30 inches; very pale brown, (10YR 7/3) fine sandy loam, light yellowish brown (2.5YR 6/4) moist; massive; hard, friable, slightly sticky, slightly plastic; few fine roots; few very fine and fine pores; strongly calcareous, lime is disseminated; very strongly alkaline (pH 9.1); gradual smooth boundary.

C2--30 to 48 inches; very pale brown (10YR 7/3) fine sandy loam, light yellowish brown (2.5YR 6/4) moist; massive; soft, very friable, nonsticky, nonplastic; few fine roots; strongly calcareous, lime is disseminated; very strongly alkaline (pH 9.4); abrupt, smooth boundary.

IIC3--48 to 56 inches; weathered shale bedrock.

In places, the surface layer is extremely stony, the A1 horizon contains 20 to 35 percent gravel and 25 to 35 percent cobbly and 1 to 2 percent stone, but below the surface layer only minor amounts of rock fragments occur.

(o) RR Rock outcrop

This mapping unit consists of exposures of bare bedrock, dominantly of sandstone. It occurs in the form of nearly vertical escarpments and also as exposed sandstone rock on more gently sloping mesa tops. These areas commonly lack vegetation but in some places stunted juniper has established in crevices or pockets of soil material.

(p) UT Ustic Torrifluvents, nearly level

This mapping unit occurs in a flood plain of an intermittent creek. It consists of about 60 percent of a coarse-loamy, mixed, mesic Ustic Torrifluvents and about 40 percent of a loamy-skeletal, mixed, mesic Ustic Torrifluvents.

These soils occur as intermixed associations along the flood plain. The coarse loamy member usually occurs on slightly higher terraces, while the loamy skeletal member occurs in the active channel.

The coarse-loamy soils are deep, somewhat excessively drained. They formed in sandy alluvial deposits from sandstone and igneous rocks. Slopes range from 0 to 3 percent. Elevation is 4,700 to 5,000 feet. Average annual precipitation is 8 to 10 inches; mean annual temperature is 48^o to 52^o F., and the frost-free season is 120 to 140 days.

The soil texture is dominantly sandy loam but ranges from loam to fine sand. Permeability is moderately rapid. Runoff is slow. Erosion hazard is high.

The loamy-skeletal soils are deep, excessively drained. They formed in gravelly and cobbly alluvial deposits from sandstone and igneous parent rocks. Slopes range from 0 to 3 percent. Elevation is 4,700 to 5,000 feet. Average annual precipitation is 8 to 10 inches; mean annual temperature is 48^o to 52^o F., and the frost-free season is 120 to 140 days.

The soil texture is dominantly very gravelly sandy loam or very cobbly loamy sand. It is highly stratified and is usually reworked during periods of runoff. Permeability is rapid. Runoff is slow. Erosion hazard is high.

Appendix D.

Computer-created maps showing eye-level and 50-foot high visibility potential of various locations related to possible mining activities. (Figure 43 in report shows the relative positions of these points).

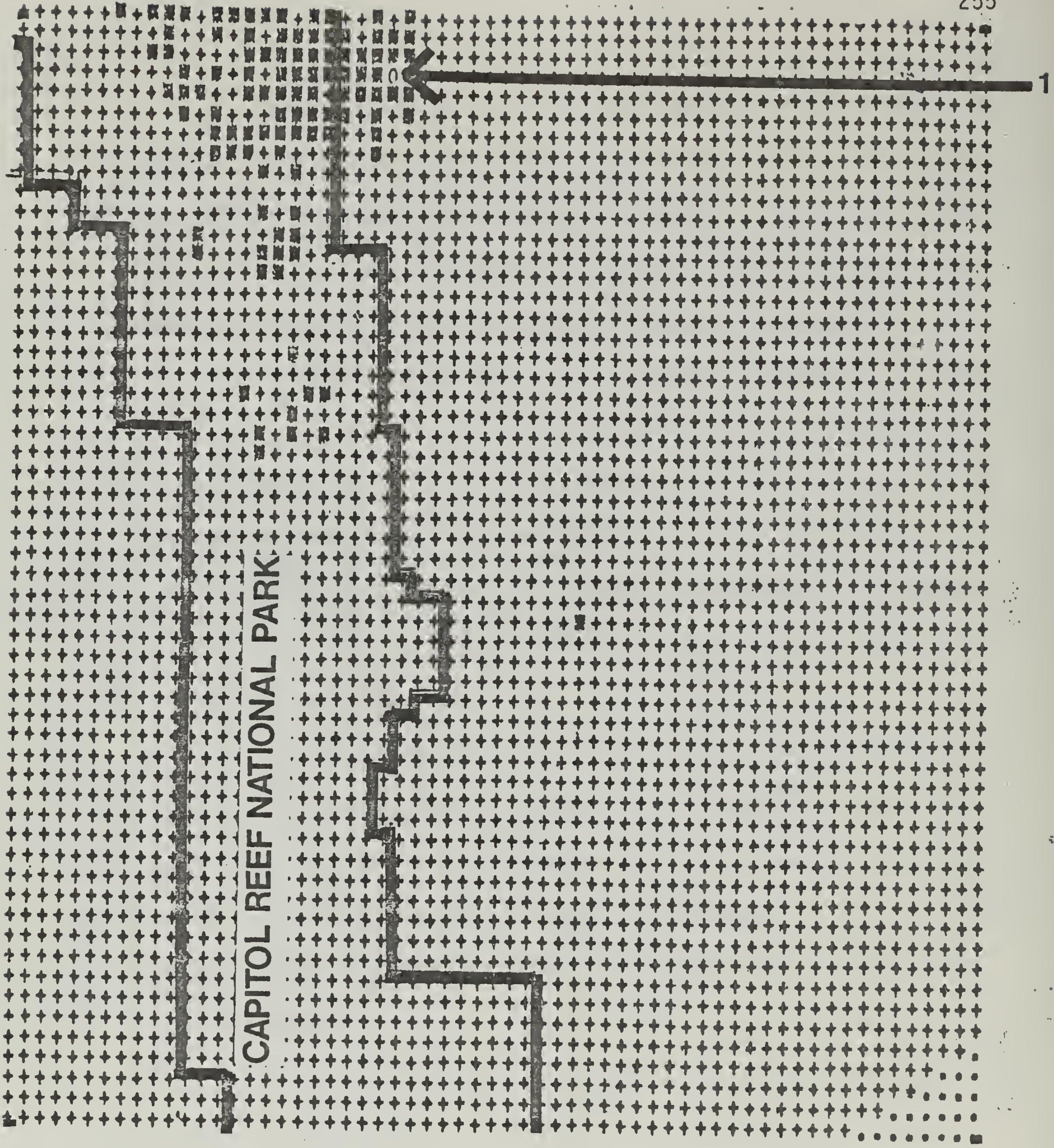

Figure No. D-1 Observation point number 1: eye level viewing height

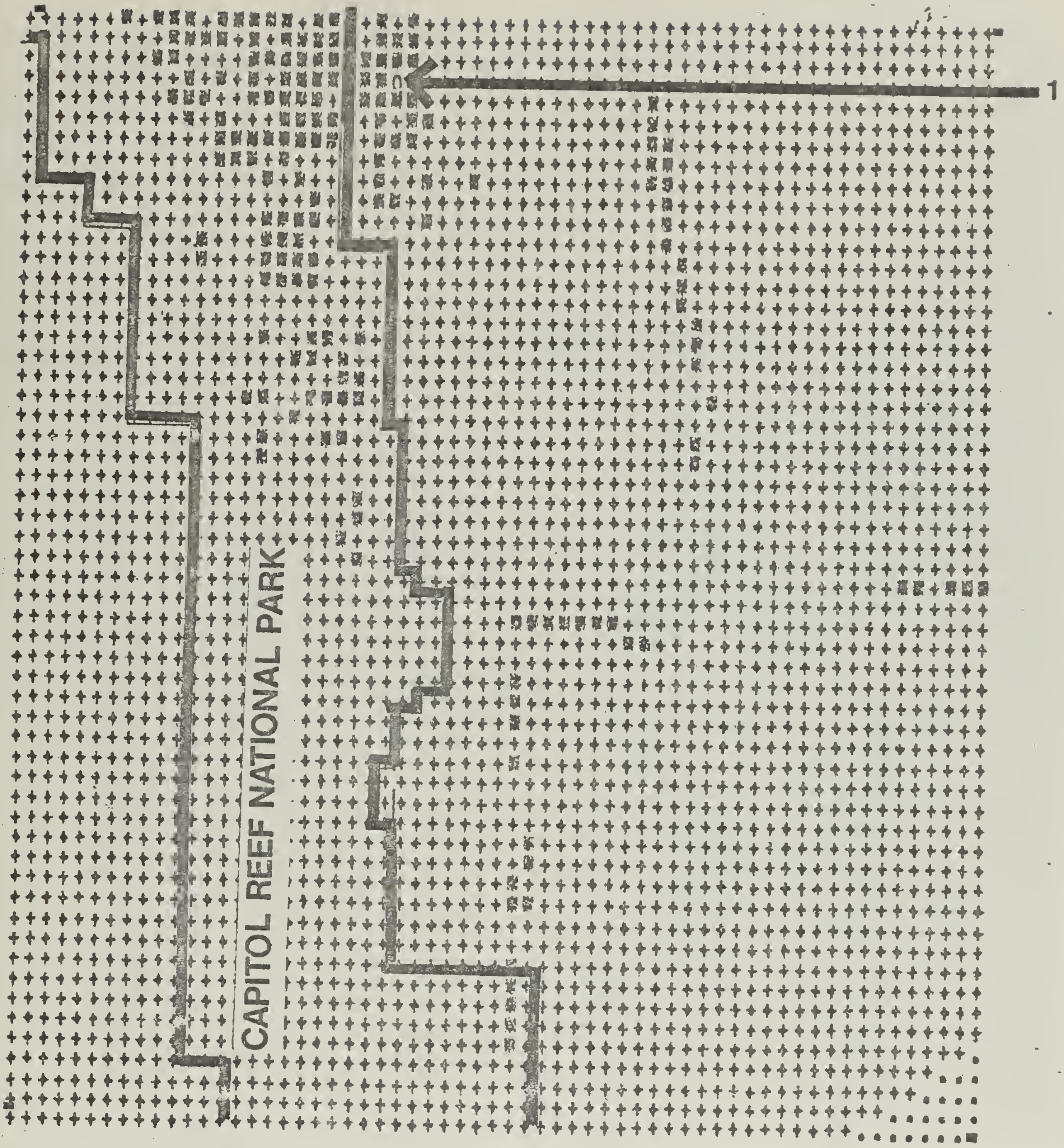

Figure No.D-2 Observation point number 1: 50 foot viewing height

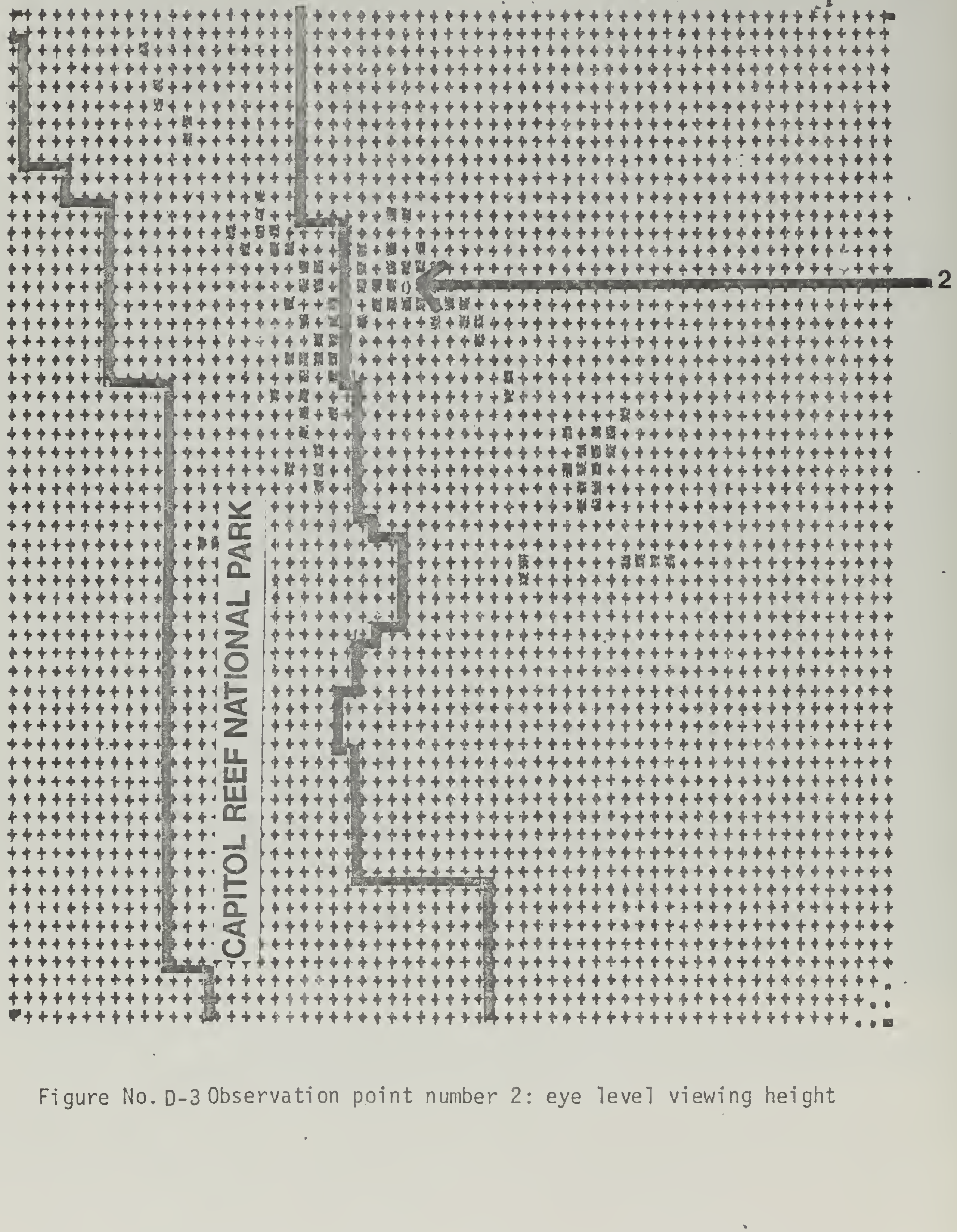

Figure No. D-3 Observation point number 2: eye level viewing height

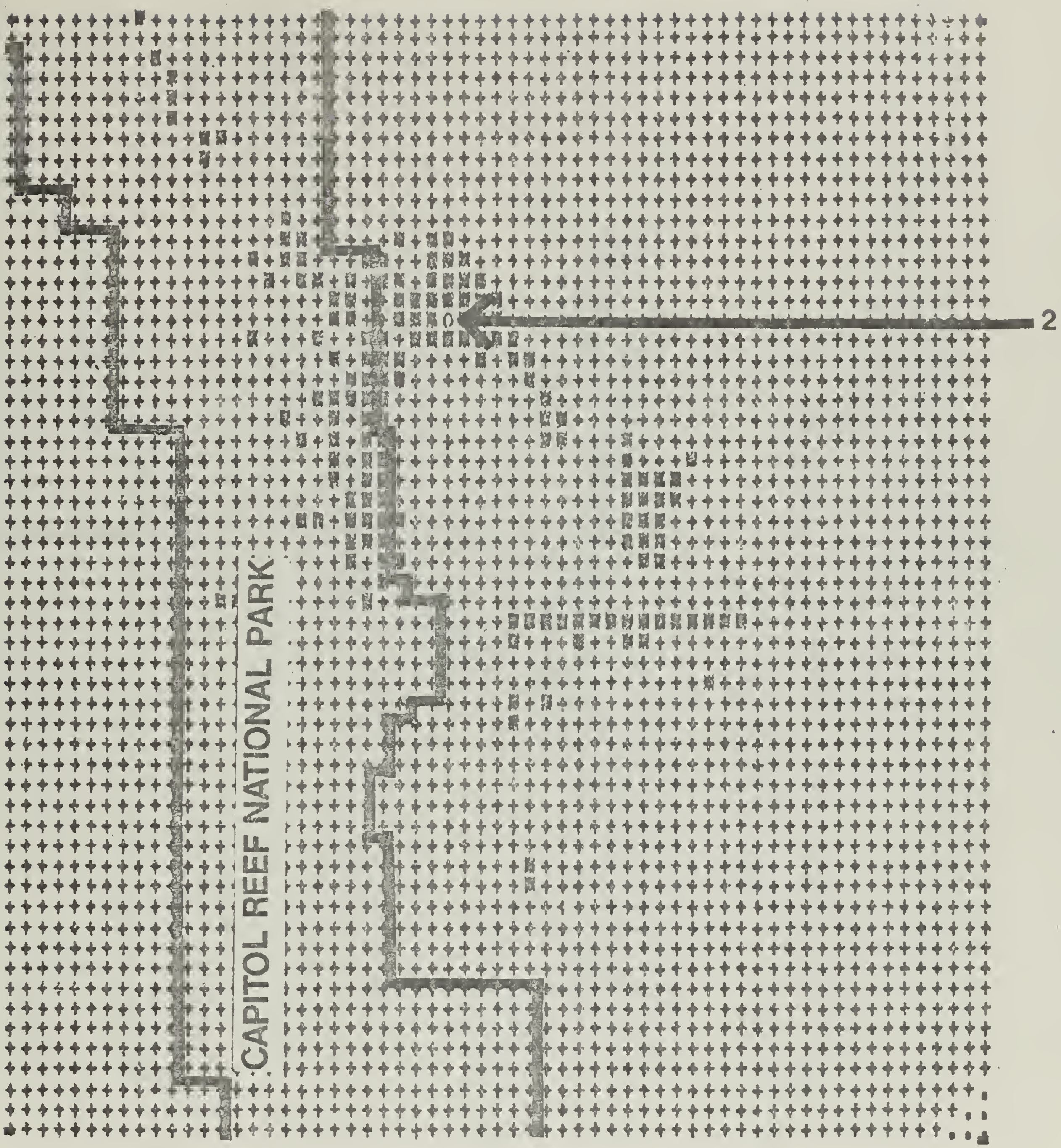

Figure No. D-4 Observation point number 2: 50 foot viewing height.

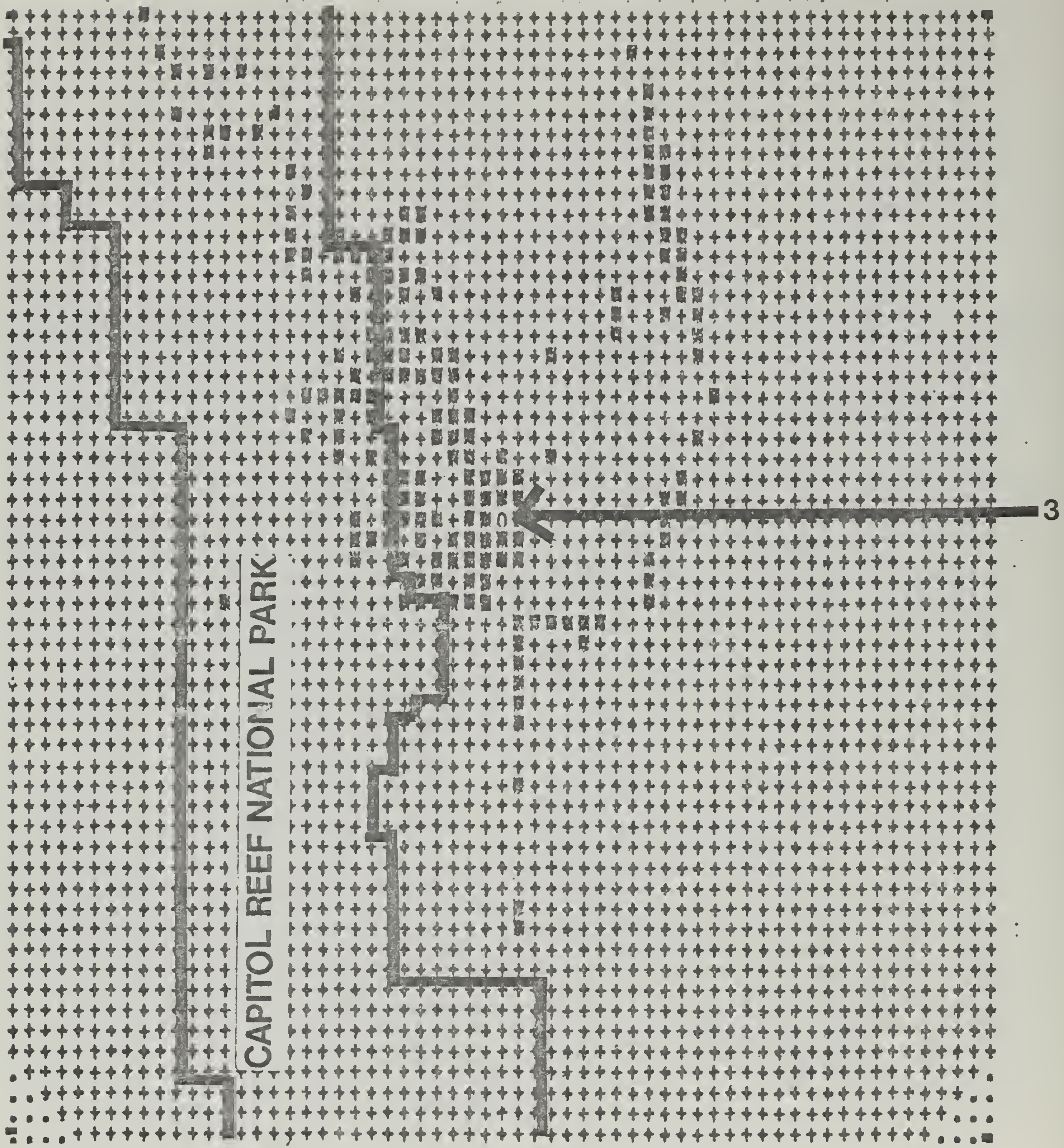

Figure No.D-5 Observation point No. 3: eye level viewing height

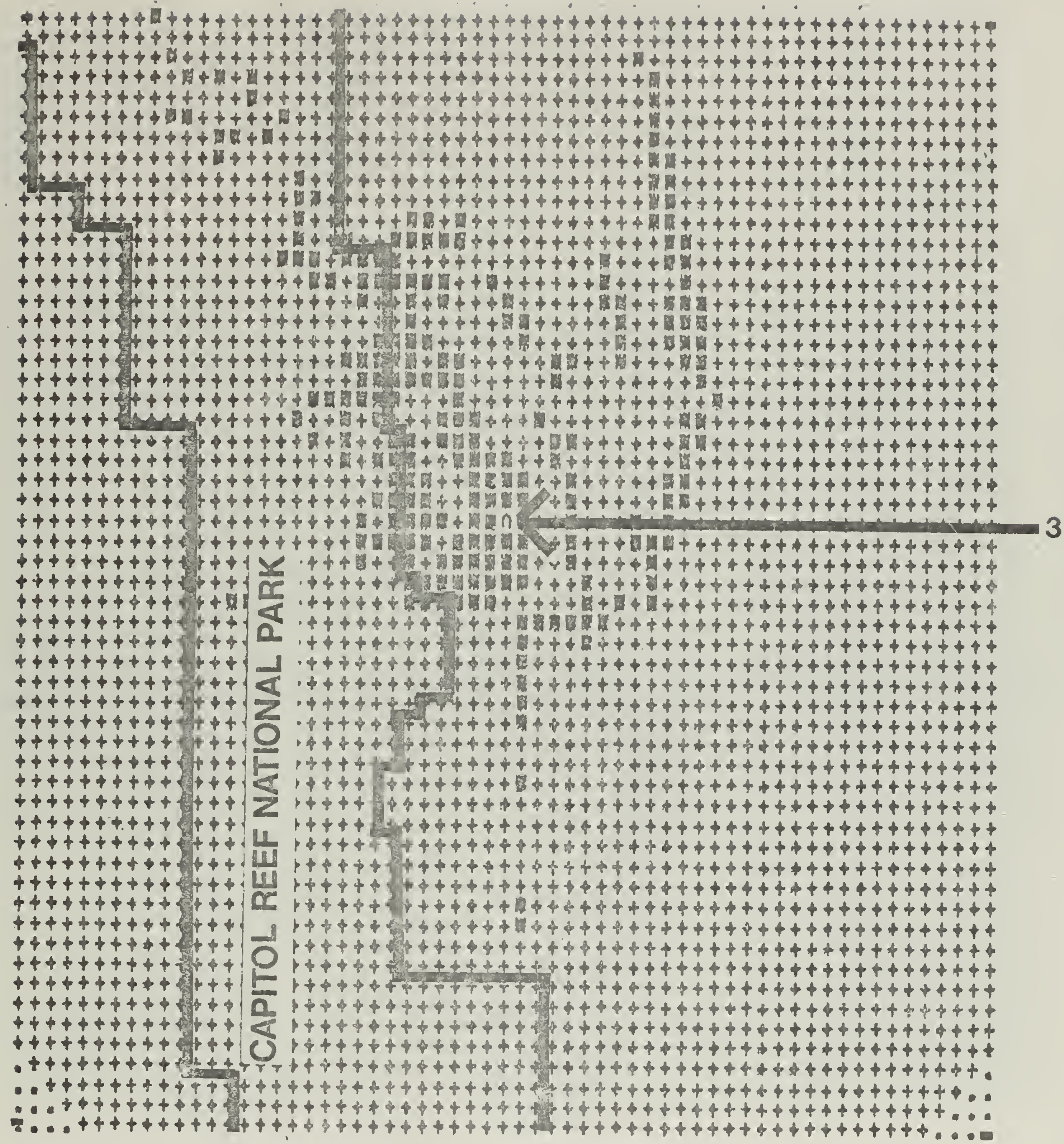

Figure No. D-6 Observation point No. 3: 50 foot viewing height

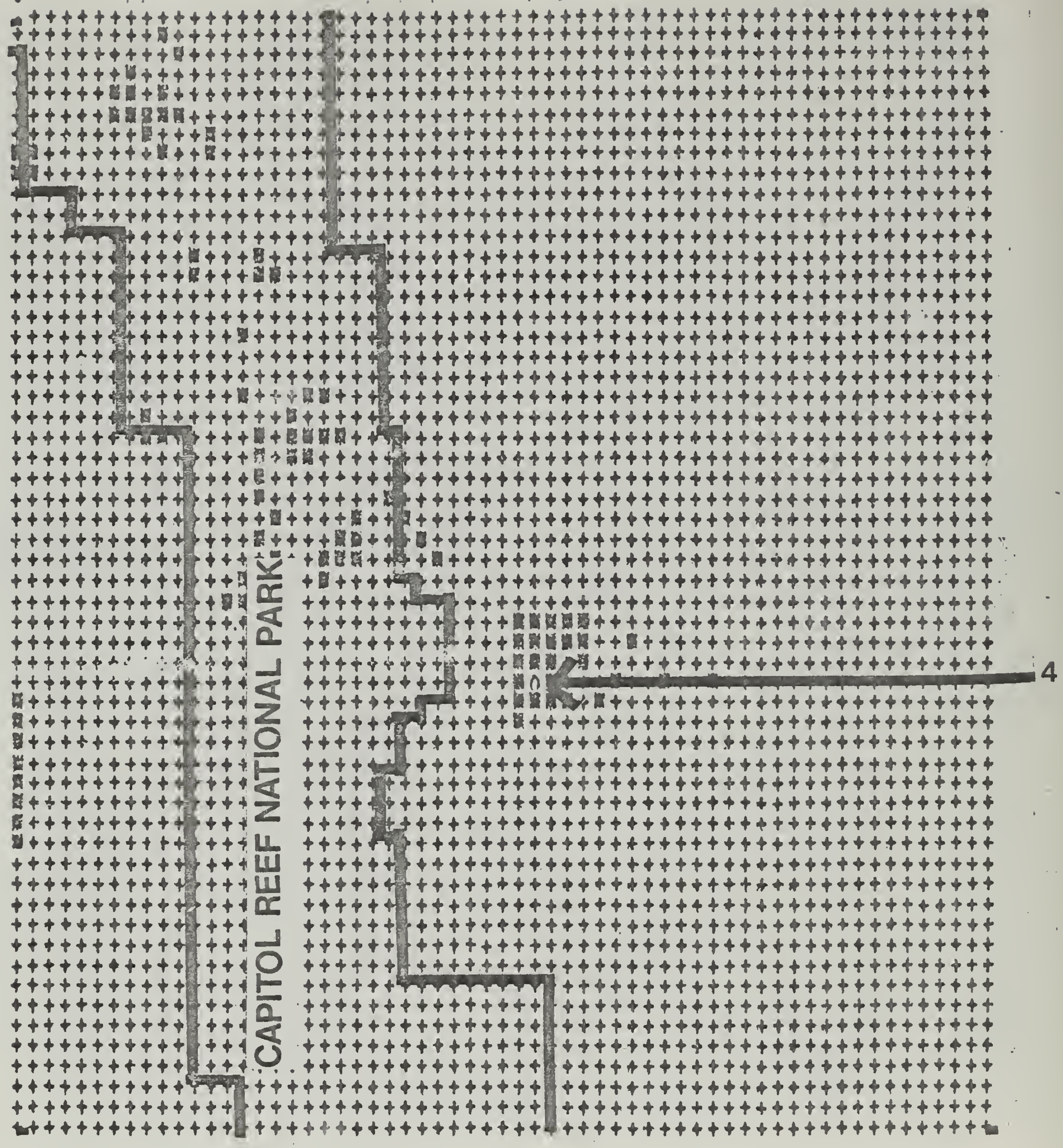

Figure No. D-7 Observation point number 4: eye level viewing height

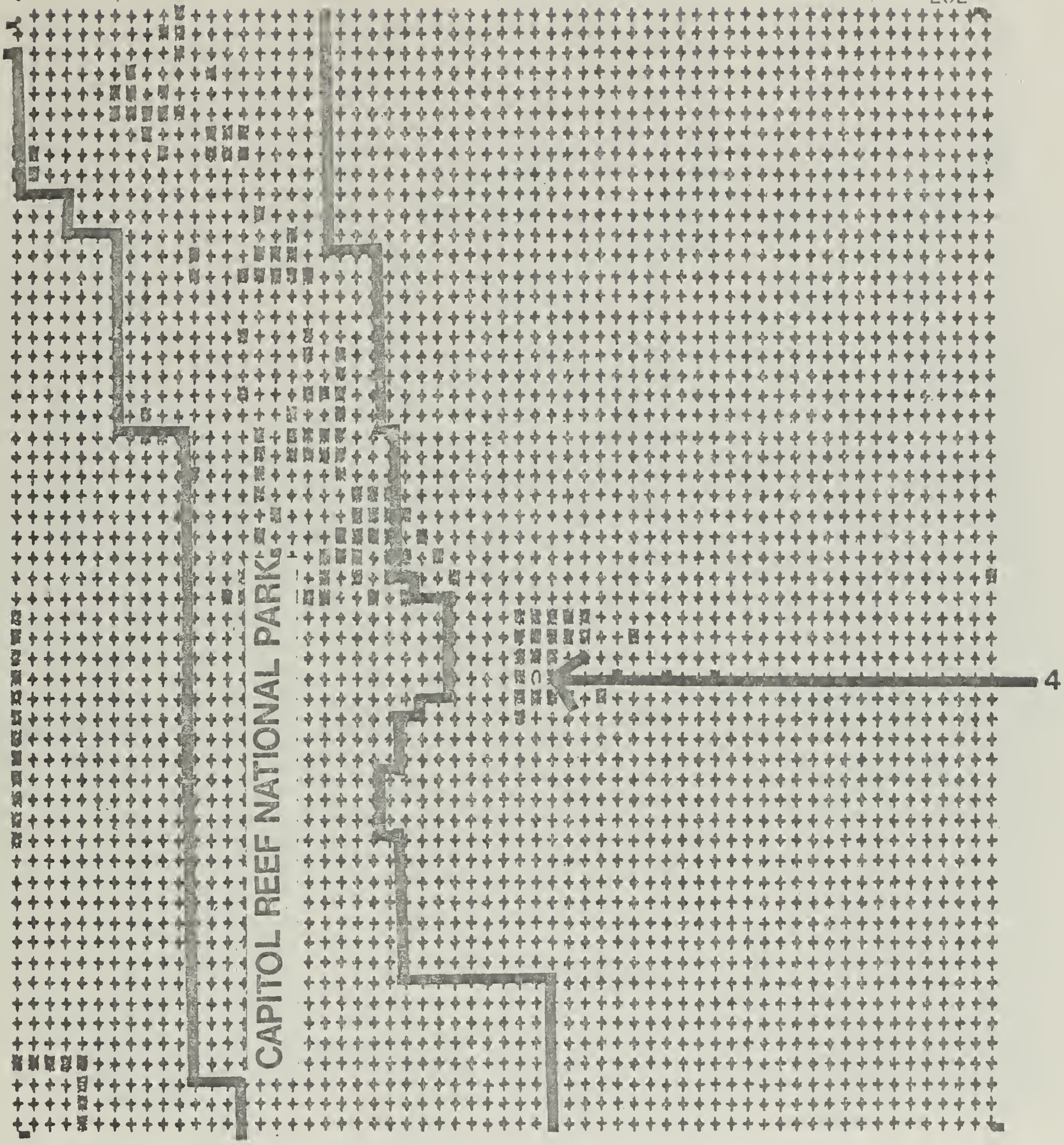

Figure No. D-8 Observation point number 4: 50 foot viewing height

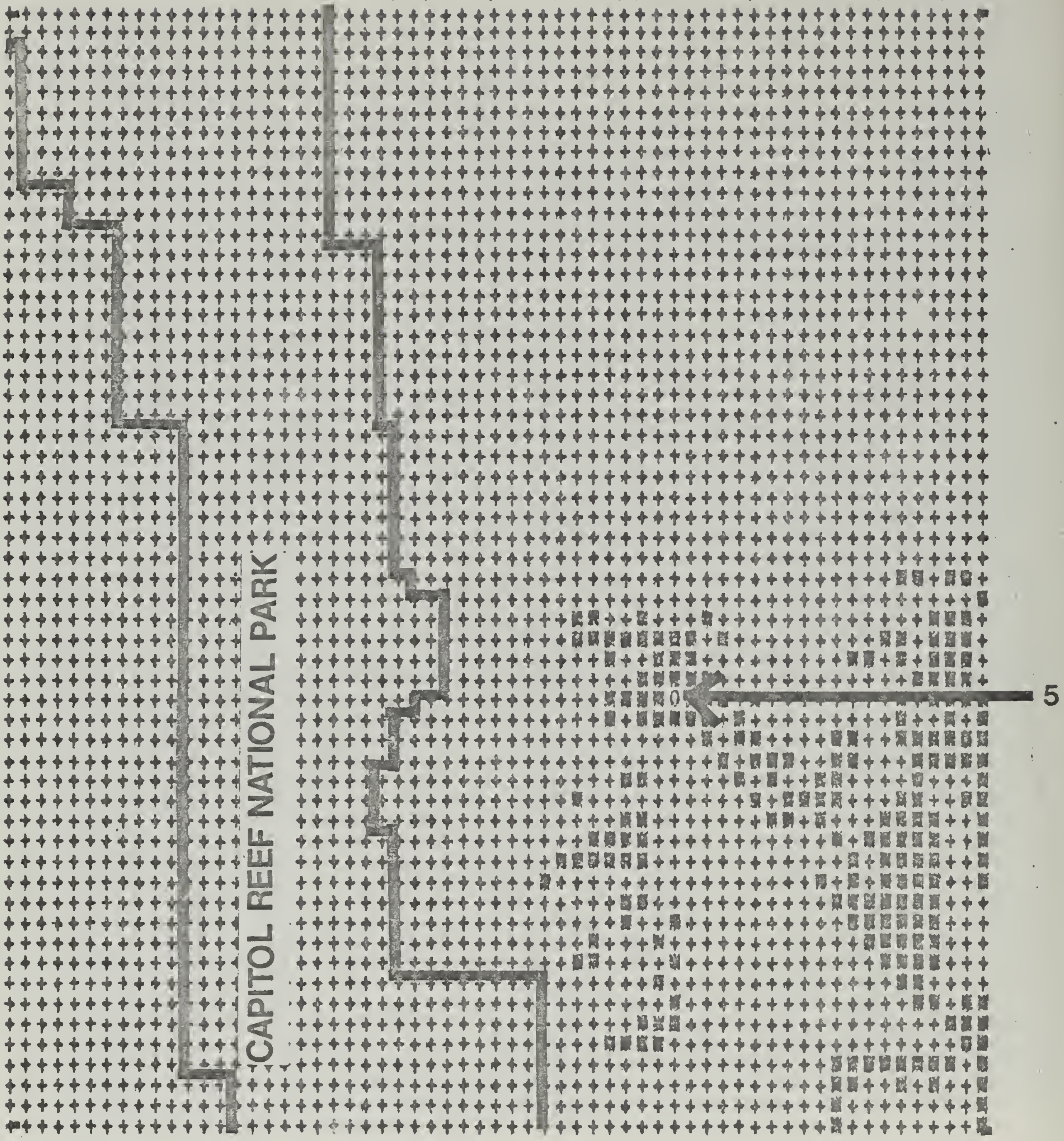

Figure No. D-9 Observation point number 5: eye level viewing height

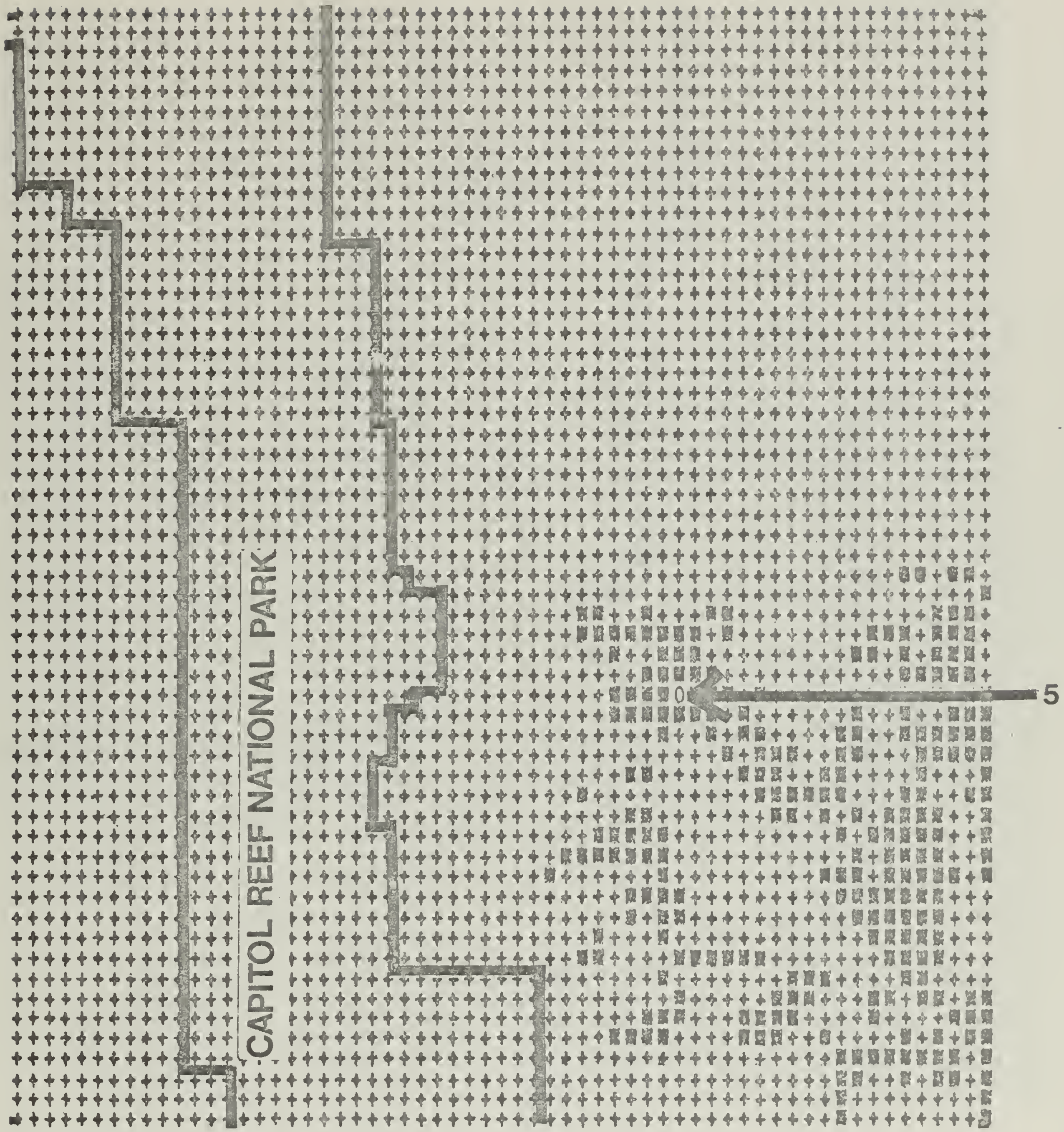

Figure No. D-10 Observation point number 5: 50 foot viewing height

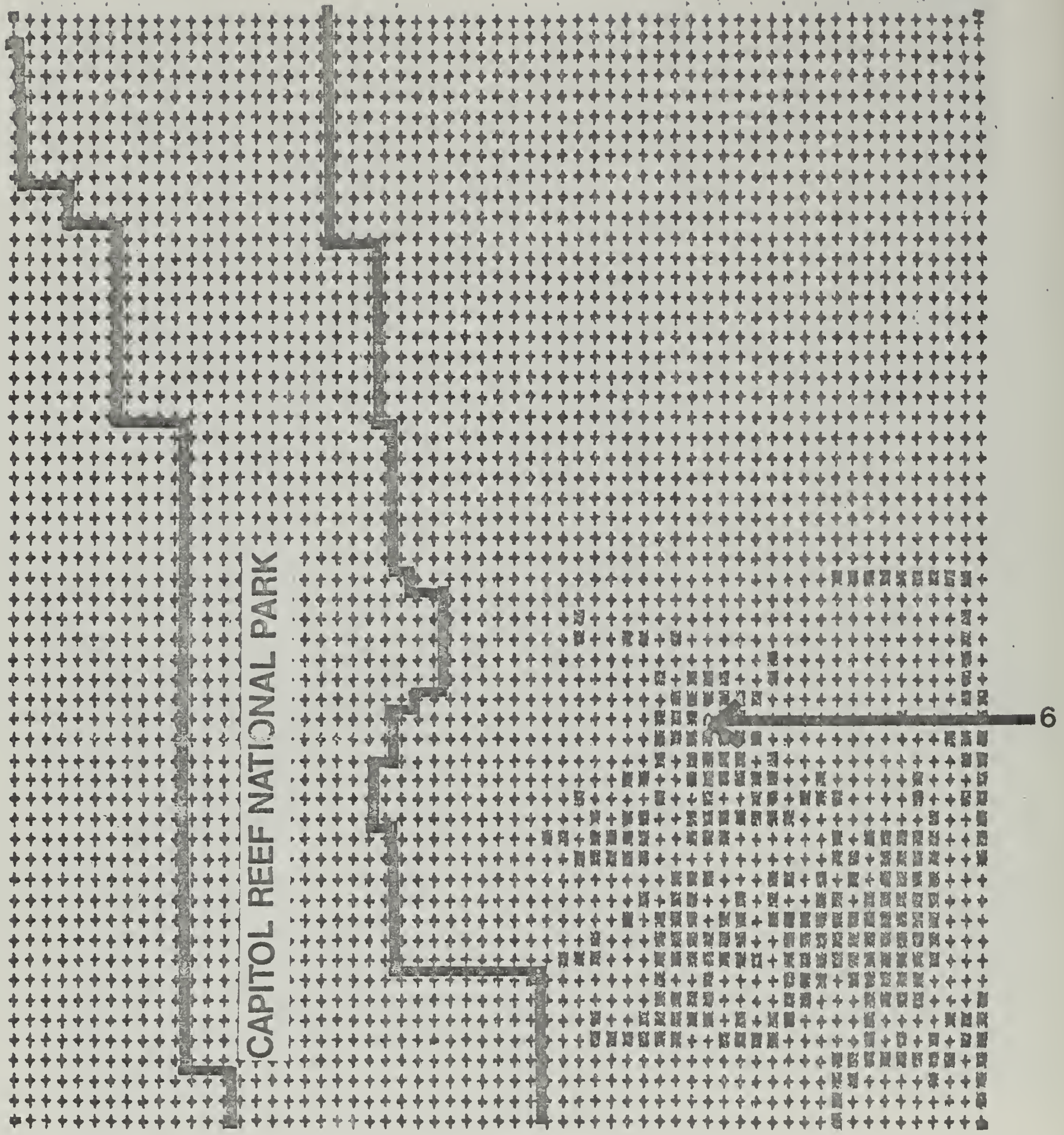

Figure No. D-11 Observation point number 6: eye level viewing height

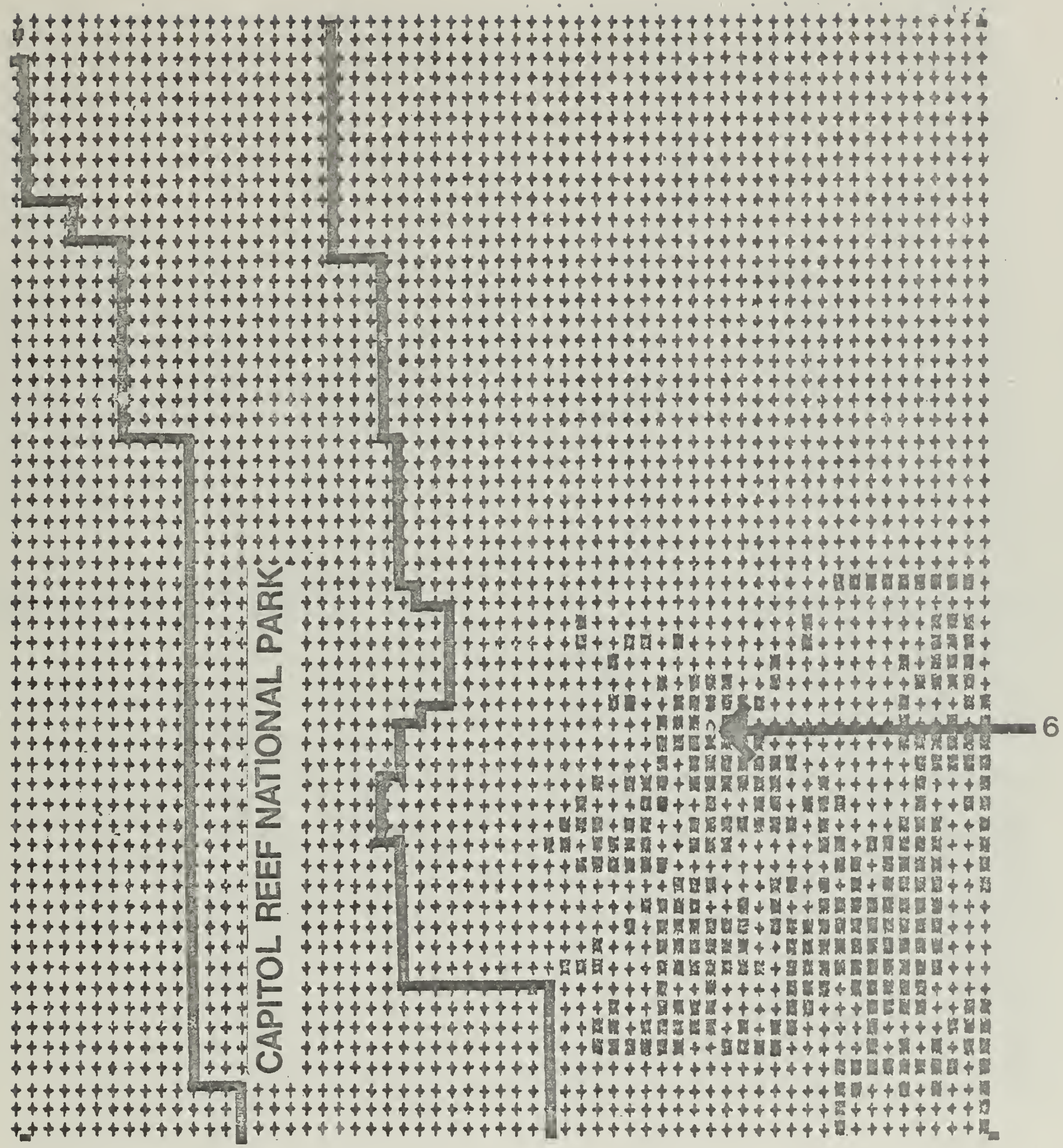

Figure No. D-12 Observation point number 6: 50 foot viewing height

Figure No. D-13Observation point number 7: eye level viewing height

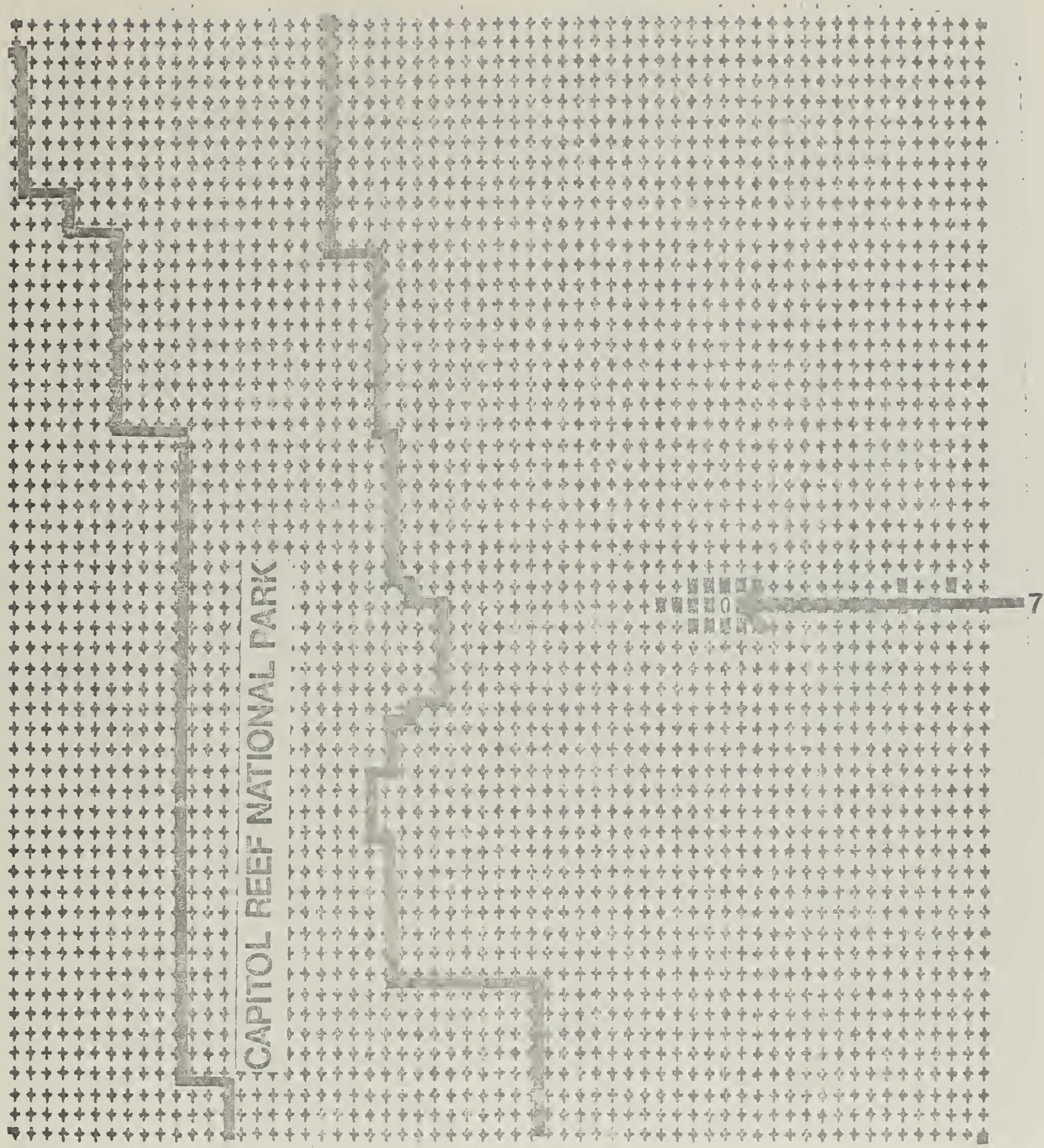

Figure No. D-14 Observation point number 7: 50 foot viewing height

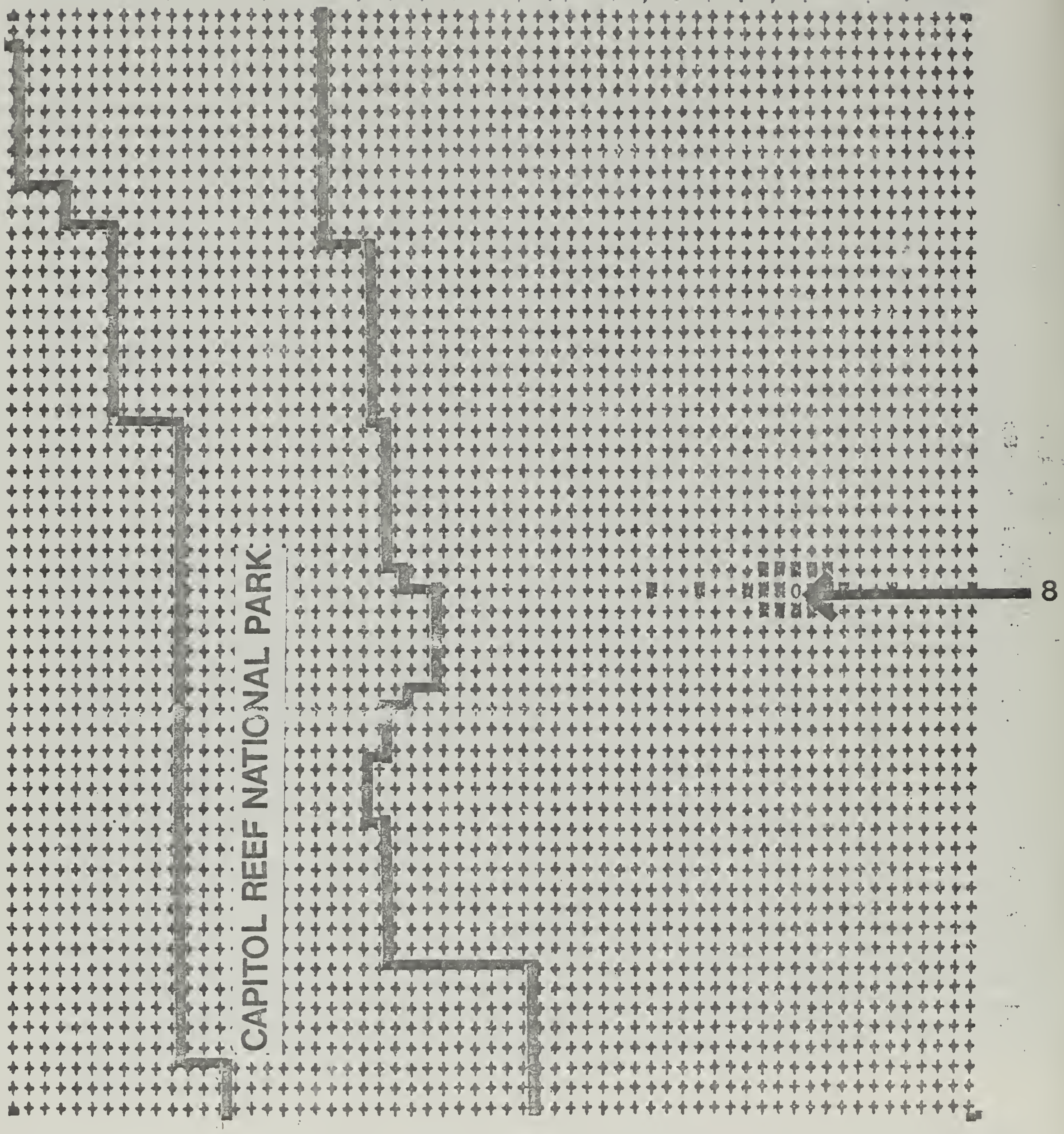

Figure No.D-15 Observation point number 8: eye level viewing height

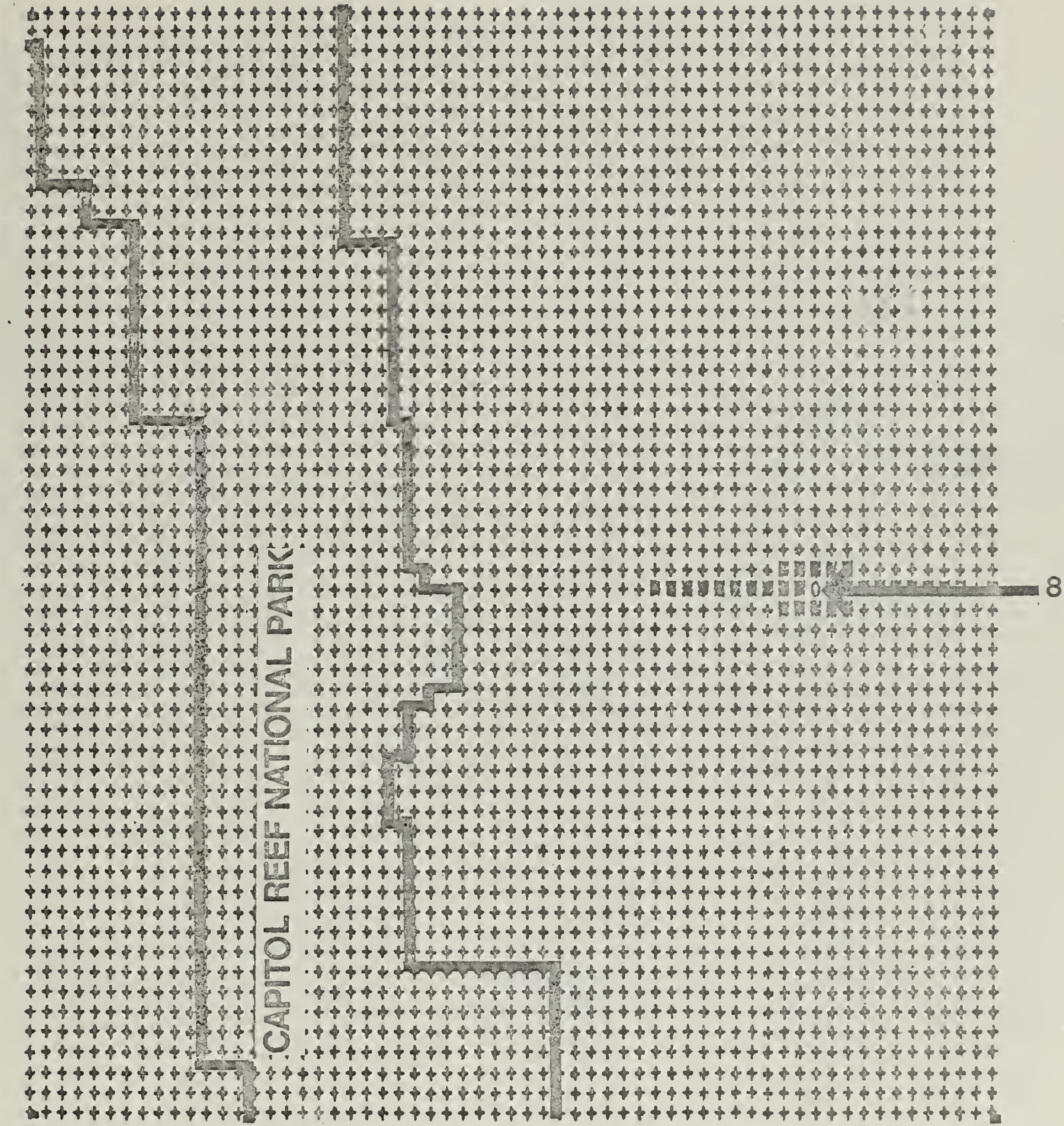

Figure No.D-16 Observation point number 8: 50 foot viewing height

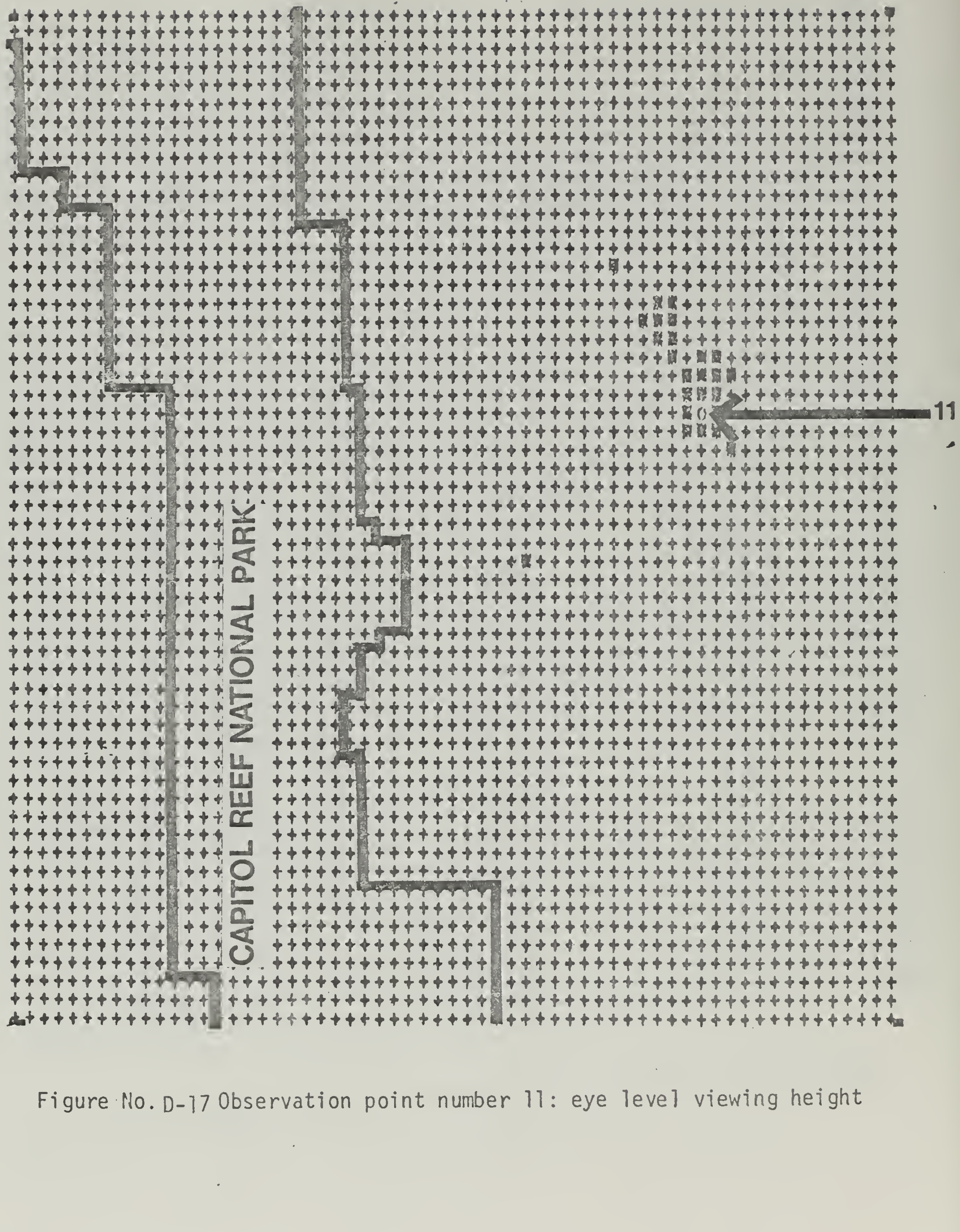

Figure No. D-17 Observation point number 11: eye level viewing height

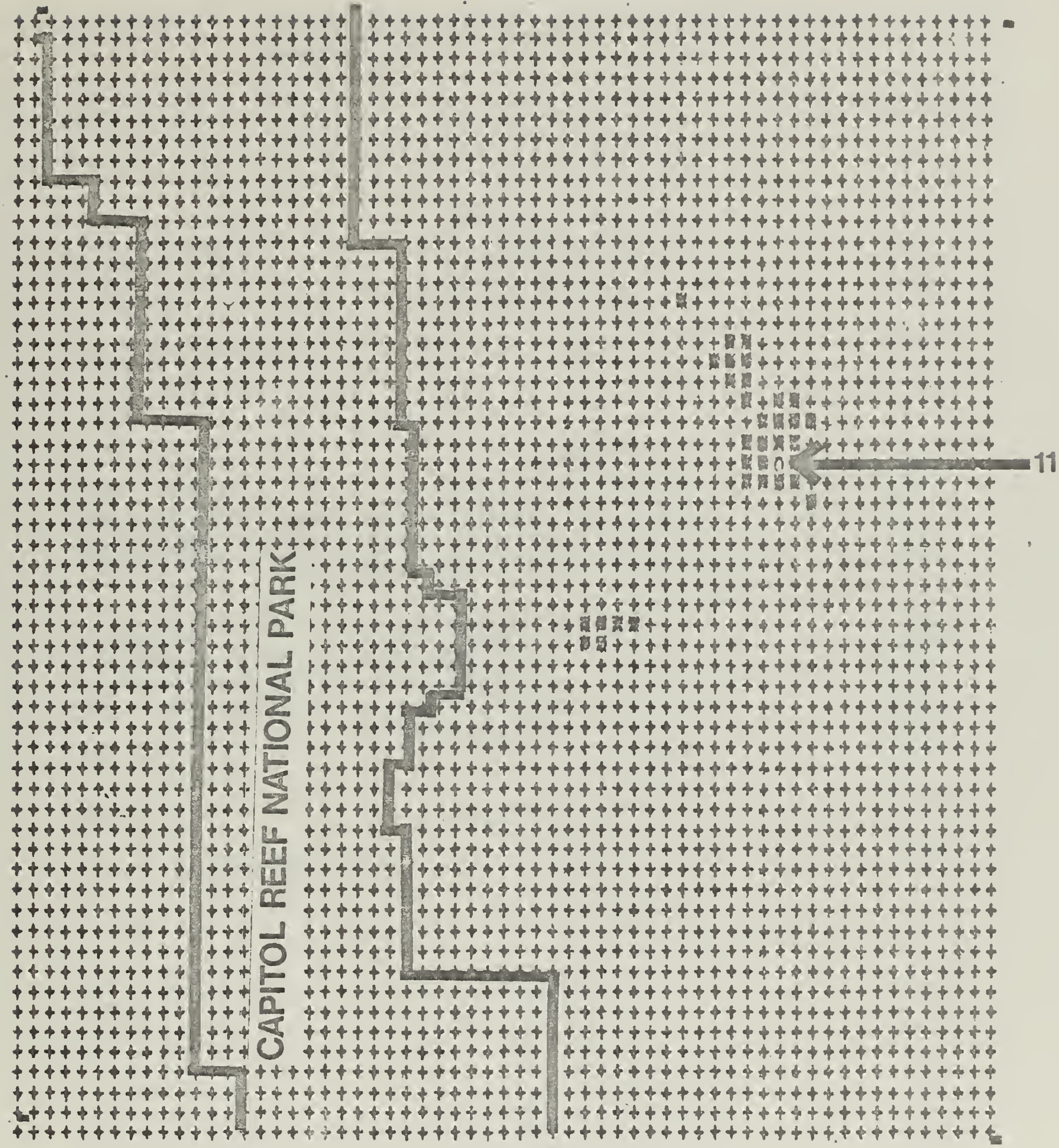

Figure No.D-18 Observation point number 11: 50 foot viewing height

Appendix E.

1. Scientific and common names of plants referred to in the Henry Mountains coal field EMRIA study.

2. A hypothetical list of common and scientific names of fauna of the Henry Mountains taken from Durrant (1952), Behle et al (1975 and Stebbins (1966).

Appendix E-1. Scientific and common names of plants referred to in the Henry Mountains coal field EMRIA study.

Common Name	Scientific Name	Four Letter Code
Alkali sacato	*Sporobolus airoides*	SPAI
Blue grama grass	*Bouteloua gracilis*	BOGR
Bottle stopper	*Eriogonum inflatum*	ERIN
Broom snakeweed	*Gutierrezia sarothrae*	GUSA
Bullgrass	*Elymus ambiguous*	ELAM
Crested wheatgrass	*Agropyron desertorum*	AGDE
Fescue	*Festuca* spp	FESTU
Galleta grass	*Hilaria jamesii*	HIJA
Globe mallow	*Sphaeralcea coccinea*	SPCO
Grama grass	*Bouteloua gracilis*	BOGR
Green ephedra	*Ephedra viridis*	EPNE
Greasewood	*Sarcobatus vermiculatus*	SAVE
Halogeton	*Halogeton glomeratus*	HAGL
Hopsage	*Grayia spinosa*	GRSP
Indian ricegrass	*Oryzopsis hymenoides*	ORHY
Juniper, Utah	*Juniperus osteosperma*	JUOS
Mormon tea	*Ephedra* spp	EPHED
Needle-and-thread grass	*Stipa comata*	STCO
Pinyon pine	*Pinus monophylla*	PIED
Rabbitbrush	*Chrysothamnus* spp	CHRYS
Russian thistle	*Salsola kali*	SAKA
Russian wildrye	*Elymus junceus*	ELJU
Sagebrush, big	*Artemisia tridentata*	ARTR
Sagebrush, black	*Artemisia nova*	ARNO
Sagebrush, bud	*Artemisia spinescens*	ARSP
Sagebrush, low	*Artemisia arbuscula*	ARAR
Saltbush, cuneate	*Atriplex cuneata*	ATCU
Saltbush, fourwing	*Atriplex canescens*	ATCA
Saltbush, mat	*Atriplex corrugata*	ATCO
Shadscale	*Atriplex confertifolia*	ATCO
Snakeweed	*Gutierrezia sarothrae*	GUSA
Spiny hopsage	*Grayia spinosa*	GRSP
Sunflower	*Helianthus annuus*	HEAN
Wheatgrass, crested	*Agropyron desertorum*	AGDE
Yellowbrush	*Chrysothamnus viscidiflorus*	CHVI

1/ Authority for names is Plummer, A. Perry, Steven B. Monsen and Richard Stevens. 1977. Intermountain range plant names. US For. Serv. Gen Tech Rep INT-38. 82 pp.

Appendix E-2. A hypothetical list of common and scientific names of fauna of the Henry Mountains taken from Durrant (1952), Behle et al (1975) and Stebbins (1966).

MAMMALS

Antelope ground squirrel	*Spermophilus leucurus*
Badger	*Taxidea taxus*
Big brown bat	*Eptisicus fuscus*
Black-tailed jackrabbit	*Lepus californicus*
Bobcat	*Lynx rufus*
Brown bat	*Myotis* sp.
Buffalo	*Bison bison*
Chickaree	*Sciurus hudsonicus*
Chipmunk	*Eutamias* sp.
Cottontail rabbit	*Sylvilagus* sp.
Coyote	*Canis latrans*
Deer mouse	*Peromyscus* sp.
Elk	*Cervus canadensis*
Gray fox	*Vulpes cinereoargenteus*
Hoary bat	*Lasiurus* sp.
Kangaroo rat	*Dipodomys* sp.
Long-tailed weasel	*Mustela frenata*
Meadow mouse	*Microtus* sp.
Mexican free-tailed bat	*Tadarida* sp.
Mountain lion	*Felis concolor*
Mule deer	*Odocoileus hemionus*
Pack rat	*Neotoma* sp.
Pallid bat	*Antrozous pallidus*
Pocket gopher	*Thomomys* sp.
Porcupine	*Erethizon dorsatum*
Red fox	*Vulpes fulva*
Ring-tailed cat	*Bassariscus astutus*
Rock squirrel	*Citellus variegatus*
Spotted skunk	*Spilogale gracilis*
Striped skunk	*Mephitus mephitus*
Western harvest mouse	*Reithrodontomys* sp.
Western pipistrelle bat	*Pipistrella hesperus*

Appendix E-2 (continued)

BIRDS

Black rosy finch	*Leucosticte atrata*
Black-throated sparrow	*Amphispize bilineata*
Bluebird	*Sialia* sp.
Blue grouse	*Dendrapagus obscurus*
Blue jay	*Cyanocitta crista*
Brewer's blackbird	*Euphagus cyanocephalus*
Chickadee	*Parus* sp.
Chukar	*Alectoris chukar*
Clark's nutcracker	*Nucifraga columbiana*
Common flicker	*Colaptes auratus*
Cooper's hawk	*Accipiter cooperi*
Crow	*Corvus brachyrhynchos*
Downy woodpecker	*Dendrocopos pubesceus*
Ferruginous hawk	*Buteo regalis*
Flycatcher	*Myiarchus* sp.
Gnatcatcher	*Polioptila* sp.
Golden eagle	*Aquila chrysaetos*
Goldfinch	*Spinus* sp.
Goshawk	*Accipiter gentilis*
Great horned owl	*Bubo virginianus*
Grosbeak	*Pheucticus* sp.
Hairy woodpecker	*Dendrocopos villosus*
Horned lark	*Eremophilus alpestris*
House finch	*Carpodacus mexicanus*
House sparrow	*Passer domesticus*
Junco	*Junco* sp.
Kestrel	*Falco sparverius*
Kingbird	*Tyrannus* sp.
Kinglet	*Regulus* sp.
Lazuli bunting	*Passerina amoena*
Magpie	*Pica pica*
Meadowlark	*Sturnella neglecta*
Mockingbird	*Mimus polyglottis*
Mourning dove	*Zenaida macroura*
Nighthawk	*Chordeilus* sp.
Pine siskin	*Spinus pinus*
Pinon jay	*Gymnorhinus cyanocephalus*
Poor-will	*Phalaenoptilus nuttali*
Prairie falcon	*Falco mexicanus*
Purple finch	*Carpodacus purpensis*

Appendix E-2 (continued)

BIRDS

Raven	*Corvus corax*
Red-shouldered hawk	*Buteo lineatus*
Red-tailed hawk	*Buteo jamaicensis*
Rock wren	*Salpinctes obsoletus*
Sage sparrow	*Amphispiza belli*
Screech owl	*Otus asio*
Scrub jay	*Aphelocoma coerulescens*
Sharp-skinned hawk	*Accipiter striatus*
Song sparrow	*Melospiza melodia*
Sparrow	*Spizella* sp.
Stettler's jay	*Cyanocitta steller*
Swainson's hawk	*Buteo swainsoni*
Thrush	*Catharus* sp.
Turkey vulture	*Cathartes aura*
Vesper sparrow	*Pooecetes gramineus*
Vireo	*Vireo* sp.
Warbler	*Dendroica* sp.
Warbler	*Vermivora* sp.
Whip-poor-will	*Caprimulgus vociferus*

REPTILES

Collard lizard	*Crotaphytus collaris*
Gecko	*Coleonyx* sp.
Gopher snake	*Pituophis melanoleucus*
Horned lizard	*Phrynosoma* sp.
Leopard lizard	*Crotaphytus wislizenii*
Racer	*Coluber constrictor*
Side-blotched lizard	*Uta stansburiana*
Spiny lizard	*Scelopurus* sp.
Western rattlesnake	*Crotalus viridis*
Whipsnake	*Masticophis* sp.
Whiptail lizard	*Cnemidophorus* sp.