REPORT ON ECONOMICS OF ENVIRONMENTAL PROTECTION FOR A FEDERAL OIL SHALE LEASING PROGRAM

REPORT ON ECONOMICS

OF ENVIRONMENTAL PROTECTION

FOR A

FEDERAL OIL SHALE LEASING PROGRAM

Prepared For

THE DIRECTOR OF NATURAL RESOURCES

OF THE STATE OF COLORADO

January, 1971

By

A SPECIAL COMMITTEE OF THE GOVERNOR'S

OIL SHALE ADVISORY COMMITTEE

STATE OF COLORADO John A. Love, Governor

DEPARTMENT OF NATURAL RESOURCES

T. W. Ten Eyck, Executive Director

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Division of Game, Fish and Parks
Division of Mines
Division of Water Resources
Geological Survey
Board of Land Commissioners
Oil and Gas Conservation Commission
Soil Conservation Board
Water Conservation Board

January 22, 1970

The Honorable John A. Love
Governor of Colorado
State Capitol Building
Denver, Colorado 80203

Dear Governor Love:

In response to a request by Mr. Reid Stone, Oil Shale Coordinator for the United States Department of the Interior, I am pleased to submit herewith a report entitled, "Report on Economics of Environmental Protection For a Federal Oil Shale Leasing Program," which has been prepared by a special committee of your Oil Shale Advisory Committee.

Sincerely,

T. W. Ten Eyck
Executive Director

TWTE/dlh

Enclosure

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I. INTRODUCTION, SUMMARY, AND CONCLUSION.

1.1 INTRODUCTION.

This report has been prepared at the request of Thomas W. Ten Eyck, Director of Natural Resources of the State of Colorado, by a subcommittee of Governor John A. Love's Oil Shale Advisory Committee, known as the "Special Committee on Economics of Environmental Protection" (the "Committee") and consisting of Messrs. John B. Tweedy (Chairman), Russell J. Cameron, Frank G. Cooley, Charles H. Prien, and Ralph Sargent. The purpose of the report is to satisfy, insofar as possible, the requirements set forth in the Memorandum dated May 28, 1970, to the Under Secretary of the Interior from Assistant Secretary-Mineral Resources Hollis M. Dole and Assistant Secretary-Public Lands Harrison Loesch.

The Memorandum of May 28, 1970, attached hereto as Appendix 1.1, directed that:

> "Specifically, the environmental requirements of returning the residue from mining and refining to the earth for further use and those involved costs will be developed between the Department and the States.
>
> * * * *
>
> "It is suggested that proposed methods of development for typical areas in each State be outlined

and selected methods for mining and processing be studied. Each outline should include the current applicable regulations for each phase of the operation, or the proposed regulations to be adopted where the current standards have not been developed in order that the resulting economic costs may be evaluated.

"Proposed methods of development should include:

(1) underground mining, with underground disposal,
(2) underground mining with surface disposal,
(3) strip mining with backfill, and
(4) in situ operations.

"Particular care shall be taken to assure that the following provisions are included:

(1) air quality standards are maintained,
(2) surface and ground water quality is maintained,
(3) restoration of the lands is commensurate with future land use plans,
(4) wildlife habitat is protected and restored for future use, and
(5) scenic and aesthetic values are to be maintained.

"The resulting studies should provide that future land use requirements will be in accordance with State and local plans for development.

"Specific requirements as to soil compaction, drainage, revegetation, and community development plans should be included in each summary in order that a complete economic evaluation of the total environmental costs may be made by the Department and by prospective lessees."

The Committee has drawn upon the resources of public and private agencies which, by reason of experience and technical competence, are knowledgeable in these matters. Active participants included Atlantic Richfield Company, Cities Service Oil Company, Colorado Geological Survey, Equity Oil Company, Getty Oil Company, Humble Oil & Refining Co., Mobil Oil Company, Shell Oil Company, Sun Oil Company, The Oil Shale Corporation, The Superior Oil Company, Union Oil Company of California, United States Bureau of Land Management, United States Bureau of Mines, United States Bureau of Sport Fisheries and Wildlife, United States Geological Survey, and various consultants in the private sector who are equally qualified. In the latter group were Cameron Engineers, Denver Research Institute, The Colorado School of Mines Research Institute, and Mr. E. H. Crabtree, a consulting mining engineer. From this assemblage a Technical Group, consisting of the following persons, was formed:

Mr. John Hutchins, Atlantic Richfield - Chairman
Mr. Harold M. Boeker, Bureau of Sport Fisheries and Wildlife
Mr. Russell J. Cameron, Cameron Engineers
Mr. Harold Carver, Union Oil Company of California
Mr. Edward H. Crabtree, Consulting Engineer
Mr. John Donnell, U. S. Geological Survey
Mr. Paul Dougan, Equity Oil Company
Mr. Eugene Hixson, Mobil Oil Company
Dr. Charles Prien, Denver Research Institute
Mr. John Rold, Colorado Geological Survey
Mr. Paul Russell, U. S. Bureau of Mines

Mr. Ben E. Weichman, The Superior Oil Co.
Mr. Frank Welder, Water Resources Division, U.S.G.S.
Dr. John Whitcombe, The Oil Shale Corporation

In discussions with the Secretarial Oil Shale Task Force and with representatives of the private sector, the Technical Group agreed on the following guidelines for the study:

(a) The disclosure of proprietary information of a confidential nature could not be expected. Nevertheless, there was available, through publications of various kinds, disclosures by industry and know-how of personnel available to this group, technical data which would enable the Committee to furnish much of the information requested by the Secretarial Oil Shale Task Force.

(b) The preparation of a detailed mining plan and design of a plant involving the expenditure of hundreds of thousands of dollars and many months' work was not feasible, and therefore the mining and processing techniques described were based on plans already in hand for other sites, or on techniques used in other segments of the mining industry.

(c) The proposed underground mining case with subsurface disposal and the underground mining case with surface disposal could be treated as a single case since there is no recognized method of storing all of the development waste and processed shale underground, except possibly where sodium minerals in substantial quantities are associated with the oil shale. Therefore, any case dealing with underground mining with underground disposal would also deal with the subject of surface disposal, and vice versa.

(d) The state of the art of processing oil shale in situ is not sufficiently advanced to provide a basis for estimates of costs of environmental protection. Nevertheless, the group concluded that a brief discussion of the status of experiments in this field would be desirable.

Technical Group members were asked to draft the various sections of this report to describe the natural resources of the Piceance Creek Basin, the oil shale mining and processing, and the related environmental aspects. The drafts and subsequent revisions were then submitted to the following governmental agencies representing the disciplines involved in managing public lands and resources:

<u>Colorado Agencies</u>
Colorado River Water Conservation District
Cooperative Fisheries Unit
Cooperative Wildlife Research Unit
Department of Public Health, Air Pollution Division
Department of Public Health, Water Pollution Control Division
Department of Natural Resources
Division of Game, Fish & Parks
Division of Water Resources
Geological Survey

<u>U. S. Department of Agriculture</u>
Soil Conservation Service

<u>U. S. Department of Interior</u>
Bureau of Mines
Bureau of Outdoor Recreation
Bureau of Reclamation
Bureau of Sport Fisheries & Wildlife
Geological Survey
  Geologic Division
  Water Resources Division

<u>U. S. Agencies</u>
Environmental Protection Agency
  Water Quality Administration
  Solid Waste Management Program
  National Air Pollution Control Administration

In addition, drafts of the report were submitted to the Colorado State University Department of Fishery & Wildlife Biology and representatives of Rio Blanco County.

Certain limitations in the scope of this report should be noted at the outset:

First: The report is, in effect, a status report, not a definitive enumeration of environmental standards. It is intended to set forth the best information available at the time of publication. The techniques, procedures, and data upon which it is based are, and should be, the subject of on-going research and analysis. The continuing studies recommended in this report are intended to supplement the data contained herein and provide a body of knowledge from which a flexible structure of regulatory standards may be devised to permit the input of new data as it is developed.

Second: This Committee is not charged with the duty of prescribing the environmental standards to be adopted by the Department of Interior and by the State of Colorado. This responsibility must rest with these governmental bodies. This report and the studies which supplement it may, however, provide background against which appropriate recommendations for meaningful environmental control standards can be evolved between Federal, State, industry, and conservation groups.

The Committee wishes to acknowledge the constructive spirit of cooperation which all of the agencies, companies, and consultants named above have shown in contributing to and reviewing the materials contained in this report. The conclusions, recommendations, and analyses contained in this report are, however, those of the Special Committee on Economics of Environmental Protection and are not necessarily concurred in by any of the individuals, agencies, companies, or consultants who assisted in the preparation of this report.

1.2 SUMMARY.

This report examines the impact of commercial oil shale operations on the natural resources of the Piceance Creek Basin and the related socio-economic consequences to determine whether or not a Federal leasing program can be initiated with adequate environmental safeguards.

The Piceance Creek Basin comprises approximately 805,000 acres of semi-arid, sparsely populated, highland area in Western Colorado. The principal agricultural use of the land is for grazing cattle and sheep. Use of the land for farming is limited because of the terrain and climate. The principal natural resources affected by an oil shale industry, in addition to the oil shale reserves, are the underground water and the wildlife resources of the area.

The underground water is contained in aquifers which underlie a major portion of the Federally-owned shale lands. Because much of the water is highly saline, it could be the source of significant environmental problems in certain types of operations. Therefore, any oil shale operation must be designed to prevent high solids content water from degrading local fresh water supplies.

The primary wildlife resource of the area is the winter deer range, which inevitably would be affected by the industrial activity generated by a leasing program. The impact on the winter deer habitat may be reduced by revegetation and by range improvement and substitution techniques.

Commercial operations to develop the oil shale deposit could include underground or surface mining. Underground mining would probably involve room-and-pillar methods, and surface mining would use conventional open pit techniques. Retorting for either mining method would likely be done by one of three existing methods. Two of these, the U. S. Bureau of Mines' gas combustion process and the underfeed process developed by Union Oil Company of California, utilize direct heating of the shale by combustion gas. The third, the TOSCO process, utilizes indirect heat transfer by circulating ceramic balls which are, in turn, heated by direct firing.

All three processes produce retort residue, the disposal of which involves environmental considerations. It will be necessary, except possibly where significant amounts of nahcolite and dawsonite are associated with the deposit and recovered in the processing of oil shale, to dispose of at least part of the residue on the surface. Considerable field work has been done on surface disposal of processed shale and additional work is in progress.

The techniques are similar to those used in construction of earthen dams and include moistening, spreading, compaction, and revegetation.

The retort residue will contain water soluble salts which must be controlled to avoid chemical contamination of local streams by either surface runoff or percolation. Water pollution and erosion by surface waters can be controlled by constructing a flood diversion system to bypass water around the disposal area and a retention dam below the residue pile to capture runoff water for reuse in residue disposal. Compaction during placement makes the disposal pile substantially impermeable to water percolation and thus inhibits water flow through the pile into underground or surface water sources.

Studies have demonstrated the feasibility of revegetation to improve appearance and provide ground cover for erosion control and wildlife support. Programs are in progress for additional studies of residue characteristics, plant selection, and vegetation procedures.

For an underground operation, it has been variously estimated that about 50 to 70 percent of the retorted residue could be placed back in the mine. This amount could be increased where the oil shale deposit contains a substantial volume of sodium minerals which are recovered. Although underground disposal has not been field tested, the environmental advantages of not disturbing the surface are apparent. However, more knowledge must be developed to determine if underground disposal is practical and environmentally preferable.

A major environmental consideration for mining operations is the possibility of encountering large volumes of saline water. This water could possibly be utilized in processing and retort residue disposal; however, any excess would require the development of satisfactory water management systems. Possible methods include grouting, reinjection into the underground water system, and purification. Any reinjection program must be accompanied by measures to prevent degradation of the underground water supplies.

In situ oil shale retorting has not been developed sufficiently to allow more than conceptual treatment of the environmental factors involved. It is possible that established environmental protection methods used in thermal recovery of conventional petroleum are applicable to in situ retorting of oil shale; however, the analogy has not been demonstrated. The effect of an in situ operation on the underground water systems must be carefully considered before such operations are undertaken.

Shale oil may not be refined to finished products in the Piceance Creek Basin, in which case it would probably be transported to major refining centers such as Chicago or Los Angeles. First generation shale plants may include upgrading facilities to remove nitrogen, which is present in unusually high concentrations in shale oil and is detrimental in many refinery processing units. Removal of the nitrogen, which is accomplished by hydrogenation, also removes essentially all of the sulfur, and the resulting product is a high quality refinery feedstock. The processing steps for nitrogen and sulfur removal are practiced in most modern refineries, and environmental control methods for these processing steps are now widely used in the petroleum industry.

One of the major concerns generated by the development of an oil shale industry in the Piceance Creek Basin would be its effect on the population and the socio-economic system of the region. Appropriate measures must be taken by Federal, State, and local agencies, in cooperation with non-governmental interests, to insure adequate resource and land use planning and regional environmental protection.

The incremental costs of environmental protection are difficult to separate from costs relating to health, safety, and convenience, and cannot be precisely determined without a definition of the regulatory standards under which industry must operate. In order to determine the magnitude of environmental protection costs, the Committee assumed that the standards would be equivalent to those applicable in other parts of the nation where ecological values are being effectively safeguarded. Assuming such standards, capital and operating costs to provide the required environmental protection have each been estimated to be approximately 7 percent of total costs.

1.3 CONCLUSION.

The Committee concludes that the principal areas of environmental concern which would be generated by commercial oil shale development have been identified and that proposed methods of dealing with these problems can be evaluated. Environmental risks can therefore be controlled by formulation of comprehensive protection standards and by requiring a lease applicant to incorporate in its plans, prior to commercial development, provisions adequate to meet those standards.

The Committee recommends that tentative environmental protection standards be formulated and included in the initial Federal leasing program in the Piceance Creek Basin. With information presently available, these protection standards can be sufficiently well defined to allow interested lease applicants to evaluate the costs of compliance and to design such standards into proposed development plans. The Committee suggests that, in addition to the requirements listed in the Memorandum of May 28, 1970 (Appendix 1.1), the following be considered in establishing the tentative standards:

(a) Pollution of the local streams and underground water reserves should be prohibited. This would include prohibiting pollution by discharge of industrial waste, release of underground saline water, and leaching of retort residue by either surface runoff or percolation.

(b) The design basis for flood control reservoirs and diversion systems upstream of disposal areas should be specified by the appropriate agency.

(c) Air quality control standards should be based on standards established or proposed for Colorado and other parts of the nation where effective air quality controls have been demonstrated. These standards should be adapted, where necessary, to meet the special conditions of an oil shale industry in the Piceance Creek Basin.

(d) Surface disposal of retort residue should be held to a practical minimum, depending upon site characteristics and demonstration that subsurface disposal is technically feasible and environmentally advantageous. Under certain circumstances, underground disposal could result in groundwater degradation. It should also be recognized that subsurface disposal of all residue is not possible because surface disposal will be required at the commencement of mining operations until a substantial mined out area is established, and that the mined area cannot contain all of the retort residue, except possibly where sodium minerals are extracted in substantial quantities.

(e) The carrying capacity of winter deer habitat adversely affected by industrial activity should be restored, as far as possible, by prompt revegetation and stimulation of remaining browse or provision for substitute browse areas.

(f) Environmental standards for off-site facilities such as water and oil pipelines, electric transmission lines, and roads should be formulated to minimize the impact on wildlife and to protect other environmental values of the region.

(g) Water conservation measures should be embodied in the planning and development of an oil shale industry.

As an additional aid in formulating the tentative standards and ultimately the definitive standards applicable to an oil shale leasing program in the Piceance Creek Basin, special importance is attached to the recommended cooperative studies described in Chapter XI of this report. In particular, a critical review of the tentative standards by conservation groups representing the public interest should be solicited promptly to insure that plans for implementation of the leasing program can benefit from the expertise of these groups prior to the commencement of industrial activity.

II. NATURAL RESOURCES

2.1 INTRODUCTION.

The unique character of the natural resources of the Piceance Creek Basin requires special attention before a full understanding of the environmental problems which will flow from the leasing of its oil shale resources can be attained.

2.2 GEOGRAPHY.

The term "Piceance Creek Basin" is generally used to describe the major topographic region in Rio Blanco, Garfield, and Mesa Counties, Colorado, which is bounded by the Colorado River on the south, the White River on the north, Colorado Highway 13 on the east, and Colorado Highway 139 on the west. This geographic feature includes the drainages of four major streams. Piceance Creek and Yellow Creek are tributary to the White River. Parachute Creek and Roan Creek drain into the Colorado River. A general map of the area is shown in Figure 2.1.

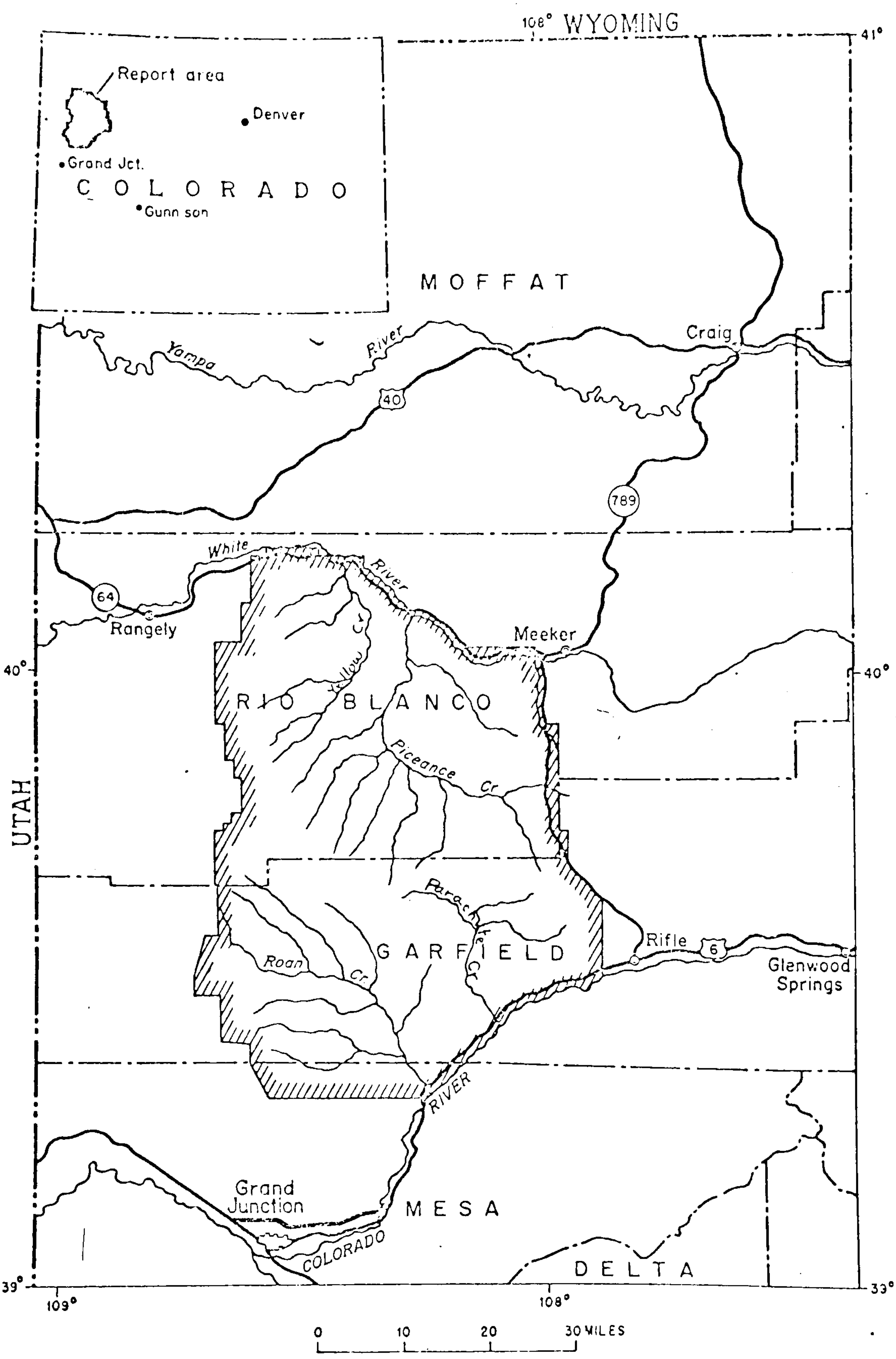


Figure 2.1 -- Index map showing report area

The distinctive topography of the area reflects a broad structural depression etched by a jointing pattern, which has produced row upon row of nearly parallel north and northeasterly oriented ridges and valleys (Appendix 2.1). Differential erosion of the underlying rock layers has created sharp ridges, low to moderately rounded hills, abrupt cliffs, and rugged badlands, interspersed with open valleys, upland parks and smaller basins.

On the west, maximum elevations include 8,420 feet near the head of Black Sulphur Creek and 8,685 feet at the head of Big Duck Creek. At the south edge there are at least five points on the Roan Plateau exceeding 8,400 feet, two of which reach 8,700 feet.

Although there is an abundance of rough terrain, the Piceance Creek drainage does not include the dramatic escarpment features of the Book Cliffs and Cathedral Bluffs which mark the Parachute, Roan and Douglas Creeks drainages.

The region's climate can be described as semi-arid. Mean annual precipitation varies from 12 inches in the northwest corner and at lower elevations to 25 inches along the high ridges in the south. Slightly less than half the precipitation occurs as snow during the months of December to April, with small amounts of rain and snow in April, May and early June. During the late summer, thunderstorms occur in a pattern starting in the vicinity of Douglas Creek Pass and the Cathedral Bluffs, then proceeding easterly and northeasterly across Piceance Creek, producing cloudbursts and highly eroding flash floods.

The region is subject to extremes in temperature due to the wide variations in elevation and exposure. During the past five years, Bureau of Land Management personnel have noted temperatures ranging from 100°F. in the summer to 40°F. below zero in the winter. Frost-free days vary from 120 near the White River to less than 50 at the highest elevations. Snow occurs over the entire area, usually starting in October. At lower elevations the snow melts early in the year; by late fall it will remain on the ground, except on wind-swept ridges.

2.3 GEOLOGY OF THE PICEANCE CREEK BASIN.

The highland, known as the Piceance Creek Basin, is underlain by the oil-shale-bearing Green River Formation of Eocene age, and the valleys bounding the area are underlain by the Wasatch Formation, also Eocene in age.

The Green River Formation consists of a series of lake deposits that attain a thickness of as much as 3,500 feet in and near the geographic center of the Basin (Figure 2.2). The lower part of the formation -- Douglas Creek and Garden Gulch Members -- contains siltstone, sandstone, fossiliferous limestone and organically poor clay shales. The upper part of the formation -- Evacuation Creek Member -- consists in great part of siltstone and sandstone with minor amounts of barren marlstone and oil shale. The middle member -- Parachute Creek -- is dominantly oil shale with minor amounts of sandstone, siltstone, clay shale, barren marlstone, thin tuff beds, halite ($NaCl$ - common salt), nahcolite ($NaHCO_3$ - sodium bicarbonate), and dawsonite ($NaAl(OH)_2CO_3$ - dihydroxy sodium aluminum carbonate). All of the oil shales of potential commercial interest are contained in the Parachute Creek Member.

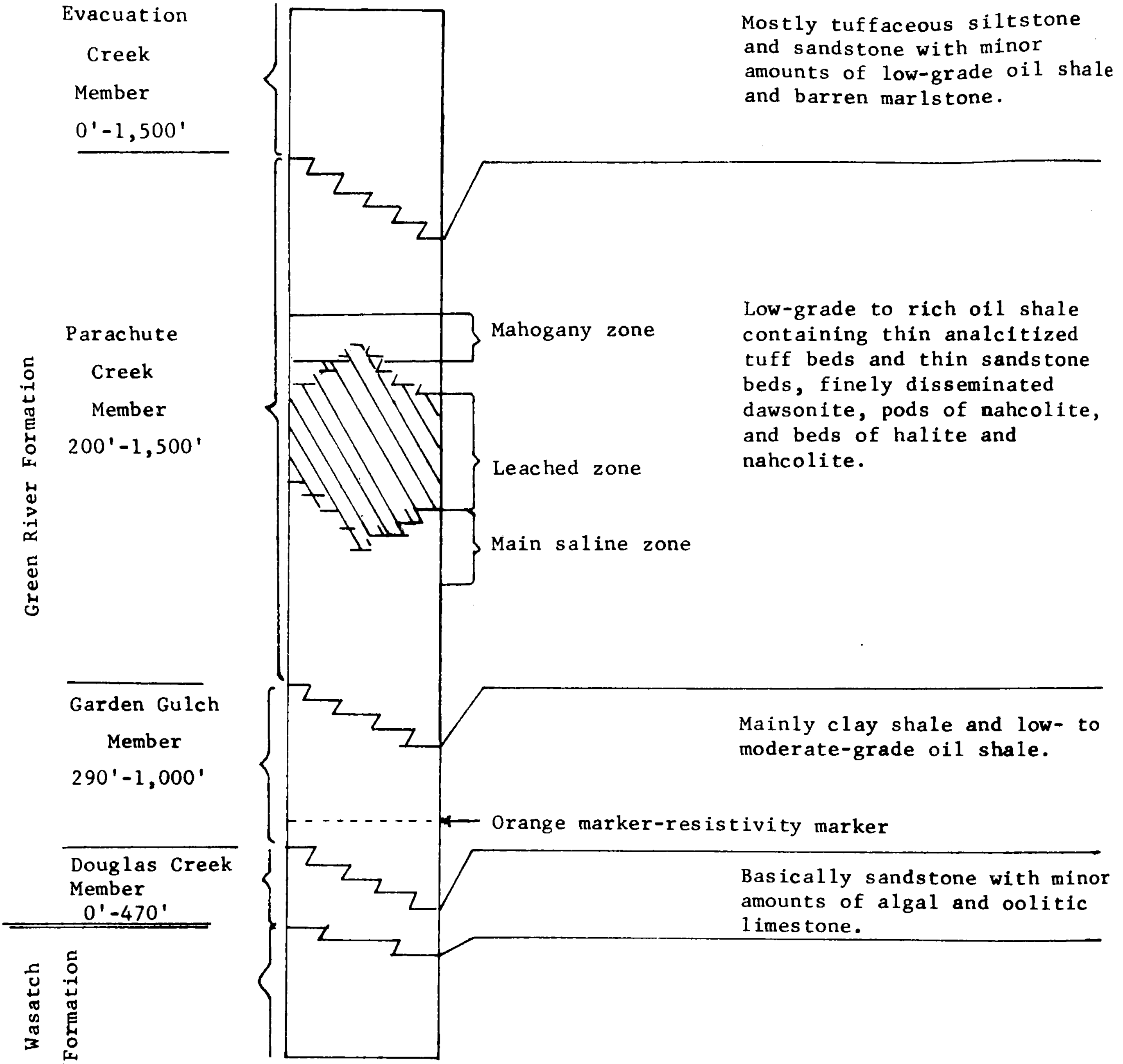


Figure 2.2 -- Generalized section of the Green River Formation in the area of the typical lease tracts

Thin beds of oil shale in the Parachute Creek Member assay as much as 90 gallons of oil per ton. Numerous zones of oil shale more than 15 feet thick, and totaling hundreds of feet in thickness, will yield an average of more than 25 gallons of oil per ton (Figure 2.3 and Appendix 2.2).

The Parachute Creek Member in the Piceance Creek Basin may be divided into two major oil shale zones. The upper zone includes the oil shale in the interval between the base of the Mahogany Ledge, the most widespread rich oil shale unit, and the base of the Evacuation Creek Member. The upper zone varies in thickness from a few feet at places along the northern edge of the basin to slightly more than 500 feet in the vicinity of Parachute Creek. A sequence of low-grade oil shale, marlstone, siltstone, or sandstone -- named "B" groove -- ranging from a few feet to more than 100 feet in thickness separates the upper from the lower oil shale zones.

The lower oil shale zone ranges in thickness from a few feet at places around the edge of the basin

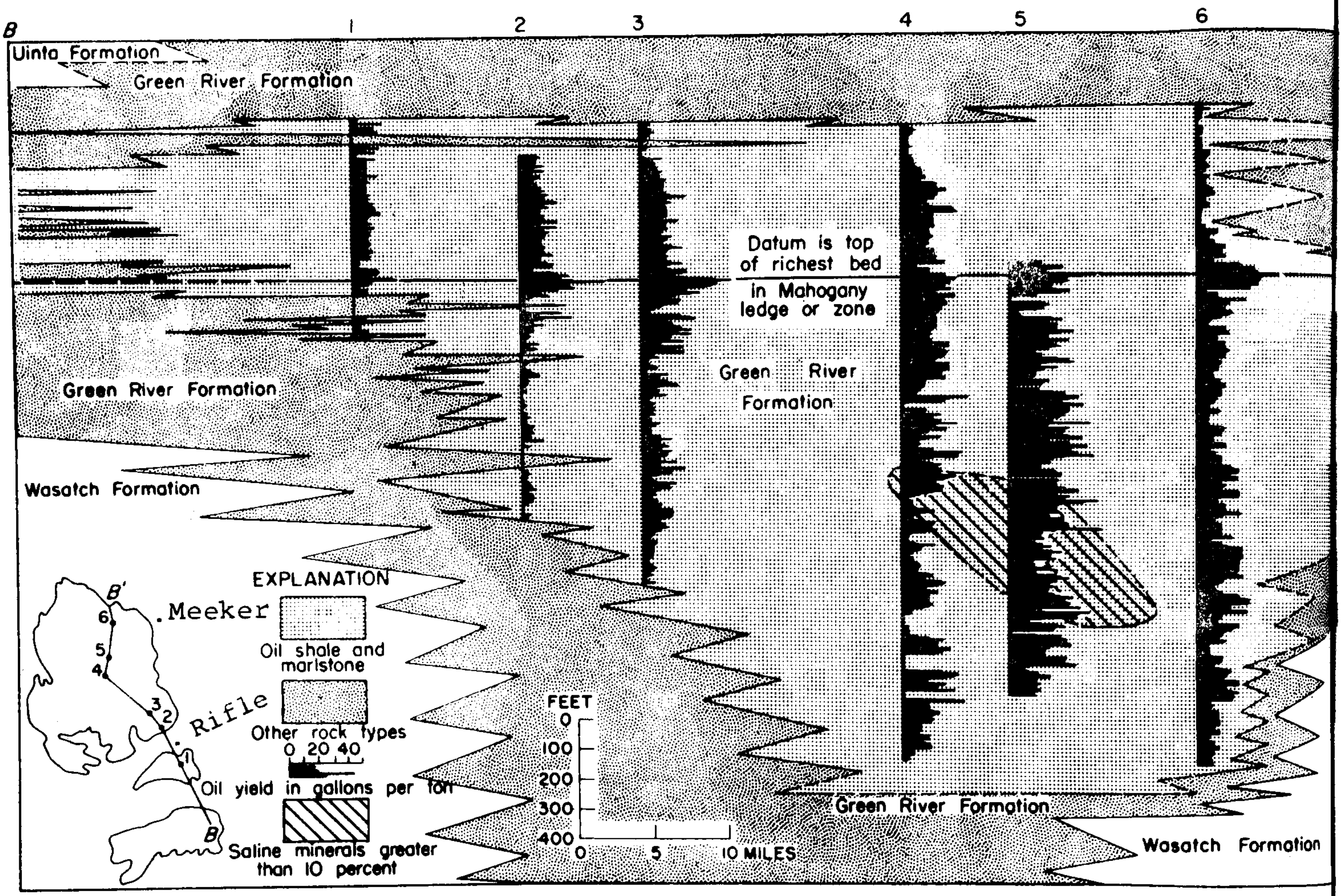


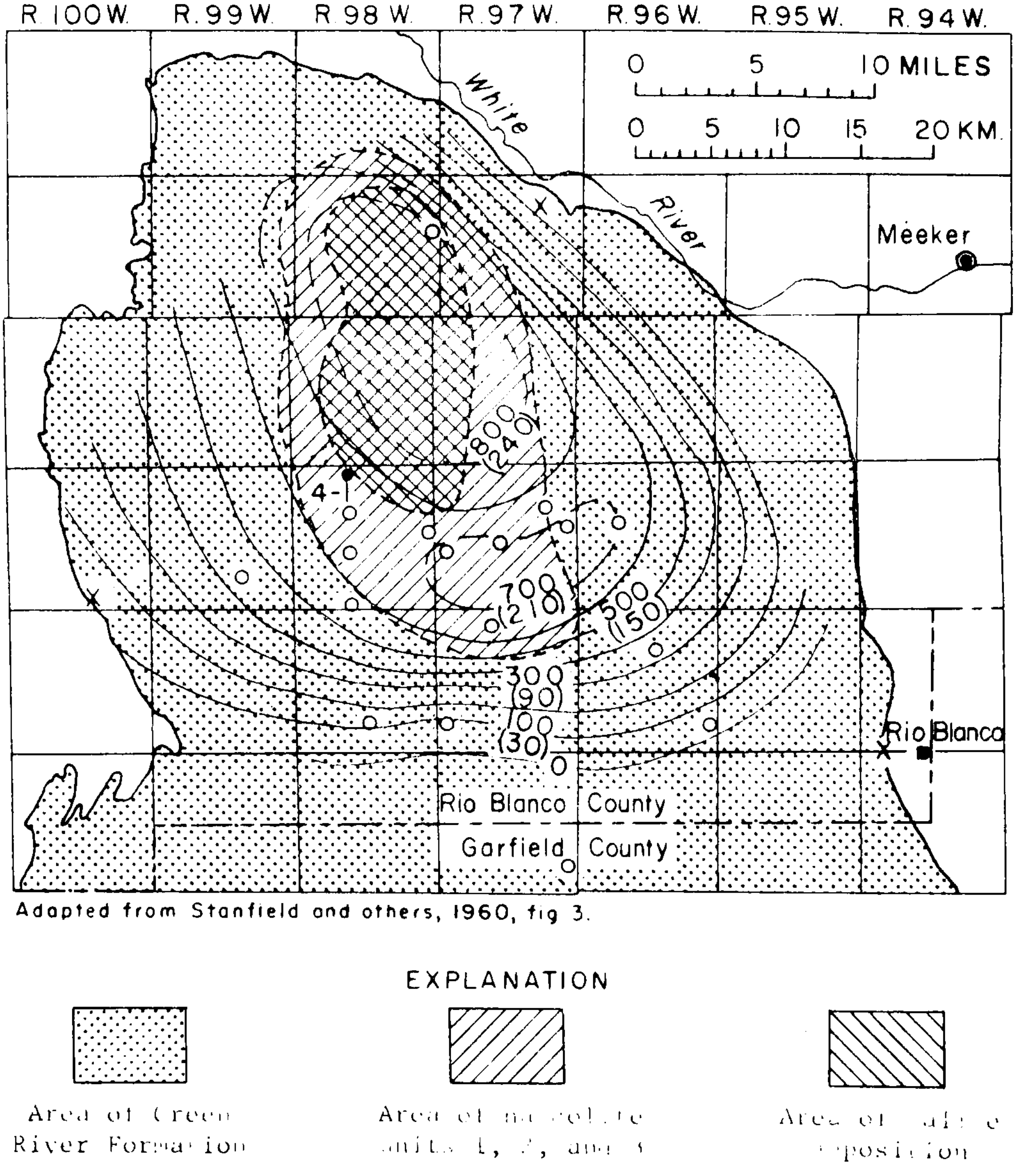
Figure 2.3 - Cross-section B-B' of Green River Formation in Piceance Creek Basin, Colorado

Point B - Located near North Mamm Peak south of Colorado River at southern extremity of Basin.

Point B' - Located on White River at northern extremity of Basin.

to more than 1,000 feet near the depositional center of the basin, and with the increased thickness there is a corresponding increase in richness of the oil shale. In limited areas, the lower oil shale zone contains several units that are as thick and rich as the Mahogany Ledge.

Most of the economically significant nahcolite and dawsonite and all of the halite is contained in the lower oil shale zone within a several hundred square mile area (Figure 2.4). This area generally coincides with the location of the Federally owned lands available for oil shale leasing (Appendix 2.2). Water percolating down into the basin has leached halite and nahcolite, and large quantities of saline water occupy the void created by the solution of the soluble minerals. The interval containing these water-filled cavities is called the leached zone and is the major aquifer in the Green River Formation. Both the upper and lower boundaries of the leached zone are extremely irregular, and the interval is several hundreds of feet thick and ranges from the lower part of the Mahogany Ledge into the upper half of the lower oil shale zone.



500
(150)

Isopachs in feet and meters (approximate) drawn on thickness of dawsonite-bearing oil shale. Isopachs are based on bore-hole data from Smith and Milton (1966) supplemented by outcrop data by D. A. Brobst, U.S. Geological Survey. Control wells are shown by circles and surface sections by X's.

Figure 2.4-Map of the Green River Formation in the northern part of the Piceance Creek basin, Colorado, showing the distribution of three nahcolite units, halite, and dawsonite and the location of the Juhan core hole 4-1.

Dawsonite is finely disseminated in the oil shale throughout much of the lower oil shale zone. In thick units near the center of the basin the rock consists of more than 10 percent dawsonite by weight. Relatively pure beds of halite and beds and pods of nahcolite are in the unleached part of the lower oil shale zone. Nahcolite in thick units in part of the basin constitutes more than 18 percent of the rock by weight.

The Piceance Creek Basin is a structural as well as a depositional basin, with dips at the margin ranging from less than half of a degree along the cliffs just north of the Colorado River to more than 10 degrees along the northern margin of the basin. A number of smaller structures -- the Piceance Creek dome and the eastern end of the Rangely anticline among them -- modify the main basinal feature.

Northwest-trending normal faults, generally occurring in pairs with a downdropped block between them, parallel the axis of some of the anticlinal structures in the northern half of the basin. Displacement along the faults is generally less than 200 feet.

Several joint systems are well developed in the basin (Appendix 2.1). The most prominent is the northeast-trending set that controls the drainages of the major northeast-flowing tributaries to Piceance Creek and the upper tributaries to Yellow Creek and East Douglas Creek. A northwest set is also well developed and controls the drainage pattern of the southeast-flowing upper tributaries to Roan Creek. The middle reaches of Roan Creek, Kimball Creek, and north and south Dry Creeks are controlled by an east-trending set of joints. The joints are open at the outcrop and the zones of weakness along which ice wedging and other means of mechanical weathering have resulted in the formation of sheer cliffs of oil shale paralleling the Roan Creek and Parachute Creek drainages, and the north side of the Colorado River. A short distance back from the outcrop, the joints are tight and in places where water has formerly seeped along the joint, access is now sealed by deposits of calcite along the joint plane. Even though these joints are tight, they represent incipient zones of weakness that may aid in a mining or in situ retorting operation by improving the fracturing characteristics of the formation.

2.4 WATER RESOURCES.

(a) Ground Water Resources.

The Parachute Creek Member, the principal aquifer of the Green River Formation, overlies the relatively impermeable Garden Gulch Member (Figure 2.5). The Parachute Creek Member and the overlying Evacuation Creek Member can be divided into four zones of different hydrologic characteristics. The lowest zone is oil shale and contains beds of saline minerals. The zone is relatively impermeable and probably little fractured. Because of its characteristic appearance on electrical logs, it is called the high resistivity zone. The characteristic high resistivity zone is confined to the center of the basin (Figures 2.5 and 2.6). The absence of this zone elsewhere may be due to low concentration of kerogen or to solution of the saline minerals. Apparently some saline minerals were deposited throughout

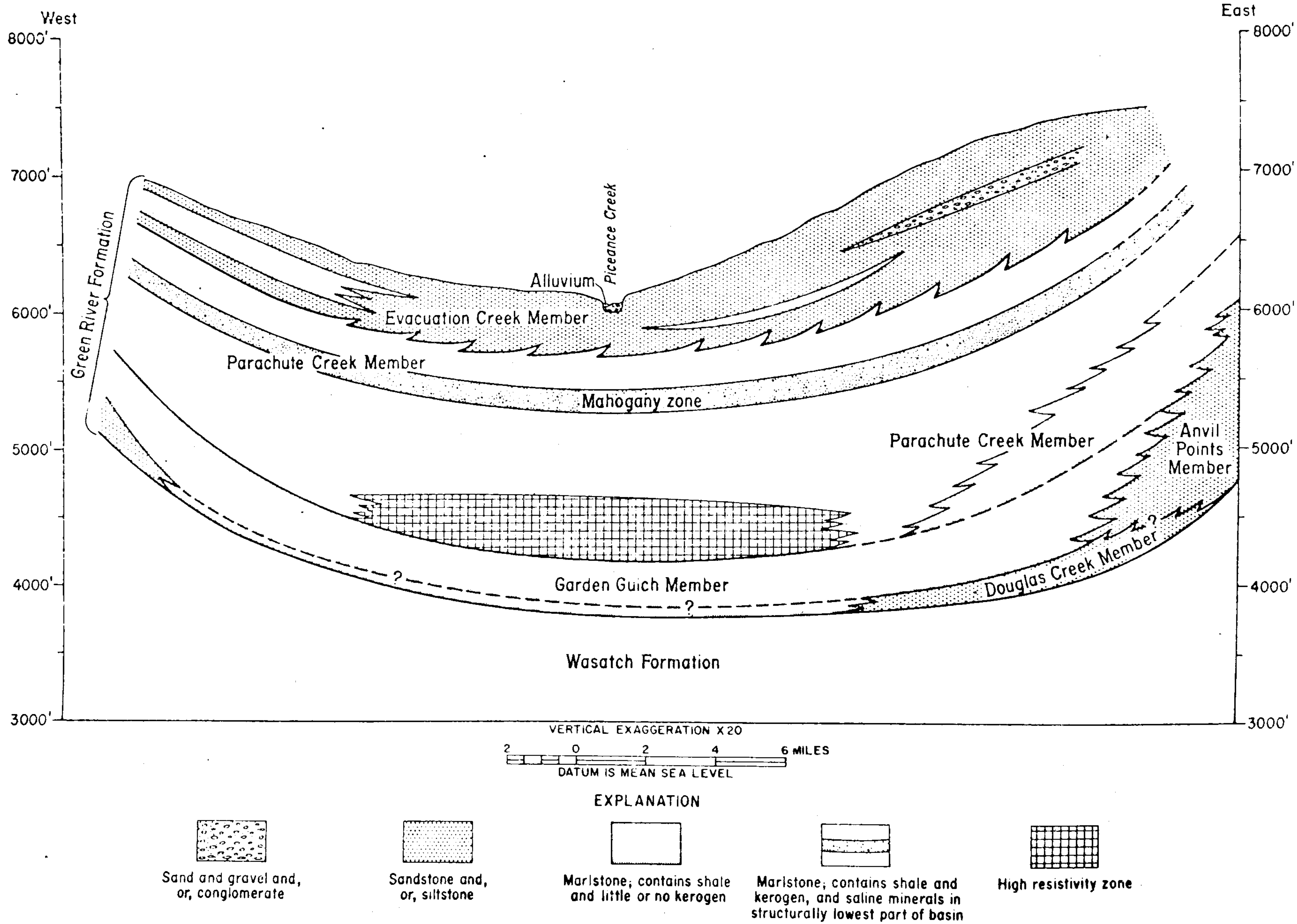


Figure 2.5 - Diagrammatic Section across the Piceance Creek Basin Showing Relations of Members of Green River Formation

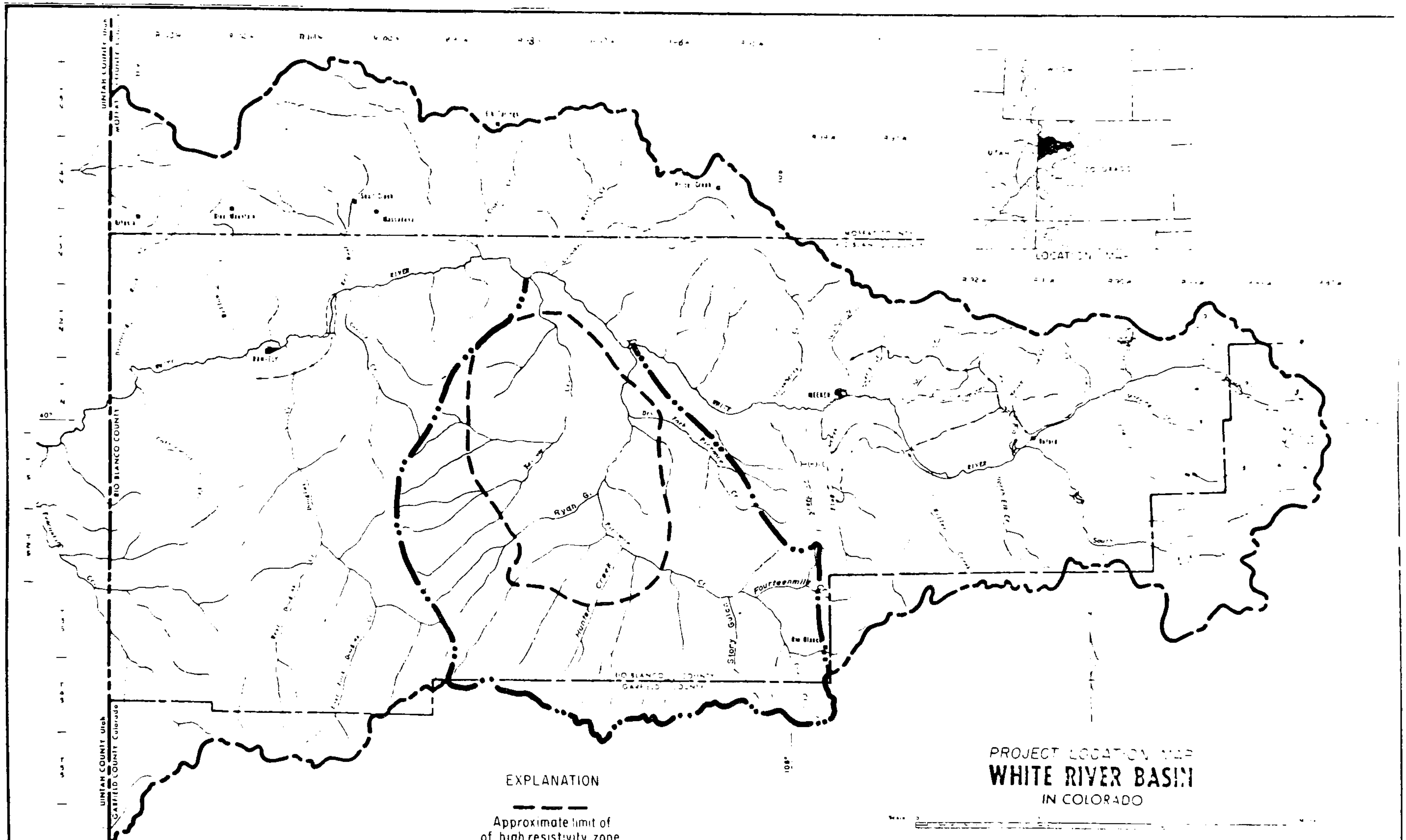


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FIGURE 2.6
MAP SHOWING
APPROXIMATE LIMIT OF
HIGH RESISTIVITY ZONE

Base map from Soil Conservation Service, 1966 the basin in the Parachute Creek Member. Deposition was most common near the center of the basin and less common on the edges of the basin; bedded saline minerals remain generally only in the deeper and thicker part of the basin.

The zone overlying the high resistivity zone is characterized by low resistivity on electric logs (Figure 2.7). In the center of the basin where saline minerals made up a greater percentage of the member, the removal of the minerals from the upper part has resulted in voids, fracturing, some collapse, and irregular bedding. The zone of low resistivity, or leached zone, is more porous and permeable than either the underlying or overlying zones; its transmissibility ranges from less than 3,000 gpd per foot (gallons per day per foot) in the margins of the basin to over 20,000 gpd per foot in the center of the basin. The leached zone is most permeable within the limits of the recognizable high resistivity zone which underlies it. The leached zone is 600 feet or more thick near the center of the basin and is the principal aquifer in the Piceance Creek Basin, yielding as much as 500 gpm (gallons per minute) to a 7-5/8 inch I. D. well.

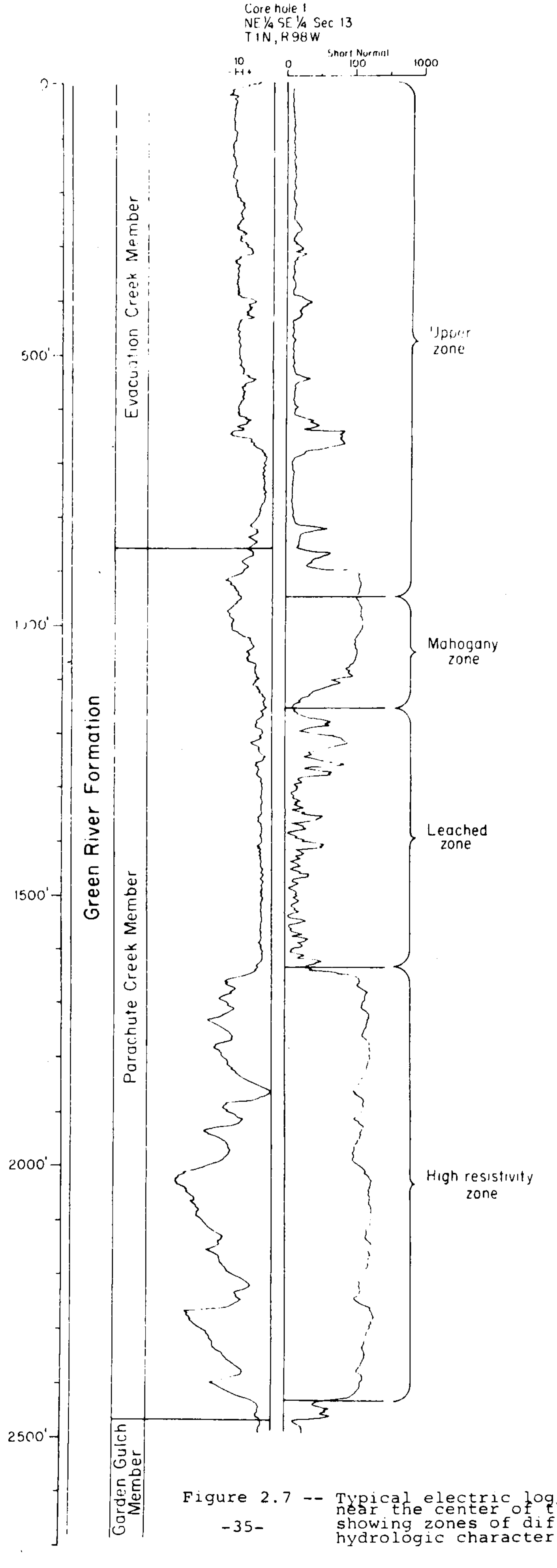


Figure 2.7 -- Typical electric log from near the center of the basin, showing zones of different hydrologic characteristics.

The Mahogany Zone is less permeable and richer in oil than the underlying leached zone. Saline minerals (or empty vugs) are sparse in this zone and apparently were never thickly deposited.

Above the Parachute Creek Member, the oil shale grades upward into fine-grained sandstone and interbedded marlstone of the Evacuation Creek Member. This member forms the surface rock throughout most of the basin and that part of the zone topographically higher than the level of the streams is mostly drained of water. Below stream level the member is saturated. A 7-5/8 inch I. D. test hole penetrating the Evacuation Creek Member in the north central part of the basin yields as much as 200 gpm. The Evacuation Creek Member appears to be more permeable than the Mahogany Zone, but less permeable than the leached zone. The Evacuation Creek Member ranges from 0 to about 1,500 feet thick.

(1) Effects of Developing Ground Water. Ground water in the northern part of the Piceance Creek Basin moves toward the two major drainages of the basin, Piceance and Yellow Creeks. The groundwater divide is

approximately the same as the topographic divide between the White River and the Colorado River on the south, Cathedral Bluffs on the west, near the Grand Hogback on the east, and near small tributaries of the White River on the main stem of the White River on the north (Figure 2.8).

Pressure data from a few wells indicate that ground water moves downward into the aquifer in the margins of the basin, laterally toward the center and northern edge of the basin, and upward in the lower reaches of Piceance and Yellow Creeks and in the White River Valley. On the northern edge of the basin, water moves upward from the leached zone and is discharged into Piceance Creek, Yellow Creek, or the White River, or is evaporated.

As previously stated, the leached zone is considered the major aquifer in the basin. Overlying zones contain and transmit water, but the few available hydrologic data indicate that the yield to a well or mine shaft in these zones will be negligible compared to the yield from the leached zone. Based upon hydrologic data from a limited number of wells, mines or wells tapping the leached zone would probably produce several thousand acre feet of

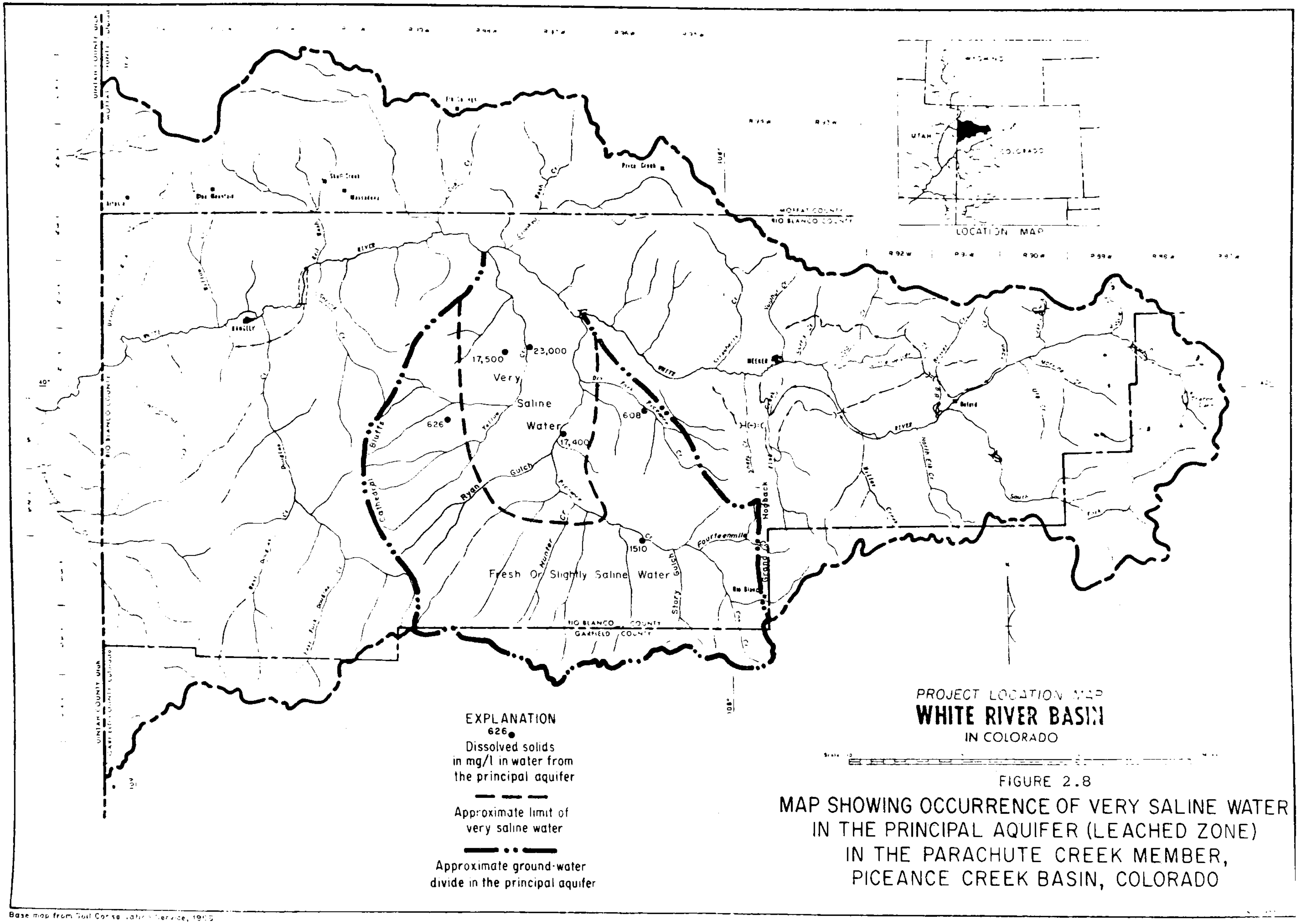


FIGURE 2.8

MAP SHOWING OCCURRENCE OF VERY SALINE WATER IN THE PRINCIPAL AQUIFER (LEACHED ZONE) IN THE PARACHUTE CREEK MEMBER, PICEANCE CREEK BASIN, COLORADO water per year for many years. Substantial declines in water levels could accompany such withdrawals, possibly resulting in the drying up of springs in areas where the leached zone is a source of such water, and possibly resulting in the compaction of the leached zone with an accompanying subsidence of the land surface.

(2) Chemical Quality of Water. Appendix 2.3 summarizes the quality of water in the White River near Meeker and at Buford. The chemical quality of water in the Upper White River is generally excellent. Specific analyses for the White River Basin were published by Iorns, Hembree, Phoenix, and Oakland (1964, p.596-600).

The chemical quality of water in the lower Piceance Creek and Yellow Creek is generally poorer in quality than the Upper White River. Reported data (Coffin and others, 1968, p.38) show that in 1964 and 1965 the water contained from 1,150 to 3,490 mg/l (milligrams per liter) of dissolved solids, principally calcium, magnesium, sodium, and bicarbonate.

Water from the leached zone near the edges of the basin generally is fresh or slightly saline. Wells near the basin edges could thus be expected to produce water having a low dissolved solids content. However, the transmissibility of the leached zone decreases toward the edge of the basin and such wells would be relatively unproductive.

Near the center of the basin, in an area overlying the central part of the high resistivity zone and extending northward to the outcrop near the White River, the leached zone contains very saline water (Figure 2.8). The principal constituents are sodium and bicarbonate, and chloride content may be several hundred mg/l. The dissolved solids content is high, ranging from 10,000 to more than 70,000 mg/l. For example, water from an abandoned oil test well in Section 28, Township 1 South, Range 97 West, contained 17,400 mg/l dissolved solids, principally sodium bicarbonate and 542 mg/l chloride (Appendix 2.4).

(b) Surface Water.

Potential sources of water for the oil shale industry in the Piceance Creek Basin include large supplies of surface water from the White and Colorado Rivers as well as ground water from aquifers within the boundaries of the basin. A small amount of water is available from streams within the basin boundaries and from the alluvium adjacent to these streams. However, these basin streams are not looked to as a reliable source of industrial water.

Estimates of water requirements of an oil shale industry have varied over the years. In 1968 it was estimated that the oil shale industry and the related urban development would require about 145,000 acre feet of water per year to produce and partially refine one million barrels a day of oil shale (Department of Interior publication on Prospects for Oil Shale Development, Colorado, Utah, and Wyoming, May, 1968). More than 700,000 acre feet of uncommitted water per year is believed to be currently available in the Colorado River Basin in Colorado, a substantial part of which can be developed from the White River near the Piceance Creek Basin. It appears that an adequate supply can be developed to support a large oil shale industry from this source.

Substantial supplies of water are available by direct flow part of the time from the White River, but much larger dependable supplies can be developed if storage facilities are constructed.

Although water for municipal and industrial uses is now available for purchase from the Green Mountain Reservoir and Ruedi Reservoir on tributaries of the Colorado River above Rifle, these and other upstream Colorado River water sources are not generally looked upon as economically competitive with water sources developed from the White River for use in the Piceance Creek drainage area. For this reason, they will not be discussed in detail in this report.

Many conditional decrees have been obtained which would permit the storage and diversion of White River water for use in the Piceance Creek Basin. An example of a project of interest to industrial water users in the northern part of the Piceance Creek Basin is the proposed Yellow Jacket Project of the U. S. Bureau of Reclamation on the upper White River tributaries.

2.5 WILDLIFE HABITAT RESOURCE.

Colorado's Piceance Creek Basin, encompassing an area of approximately 805,000 acres, constitutes one of the state's most important mule deer range areas. It serves as the principal wintering grounds for the migratory White River herd which summers on high National Forest lands to the east and for a large percentage of the migratory population utilizing summer range on the Roan Plateau (Book Cliffs) area to the south. Rough estimates suggest this basin provides at least a portion of the winter forage for up to 15 to 20 percent of the total state deer population.

Within this important area is currently found a combination of vegetative, climatic, and cultural conditions adequately providing for basic mule deer habitat needs. The broken topography of valleys, streams, and mesas offers wildlife a broad variety of slopes, exposures, and vegetative communities. Large acreages of pinyon-juniper forest are interspersed with sagebrush-dominated open parklands and irrigated streambed meadows. The well vegetated rangeland contains a wide variety of grass, forb, and woody browse species of sufficient quality and density to accommodate large numbers of wintering animals. Individual browse species of particular importance to mule deer, and found in significant quantity, include serviceberry (*Amelancier alnifolia*), mountain mahogany (*Cercocarpus montanus*), antelope bitterbush (*Purshia tridentata*), and big sagebrush (*Artemisia tridentata*).

Numerous game-range studies conducted on mule deer populations have generally confirmed that in range areas north of 36° N. latitude major habitat limitations are found within winter use zones. This winter range limitation appears to be particularly applicable to the White River and Roan Plateau herds. At 39.5° N. latitude, a line generally transecting the Piceance Creek Basin, the greater portion of range habitat suitable for mule deer winter use is found within the elevational zone ranging from 5,500 to 7,500 feet. It is significant that approximately 95 percent of the land area within the Piceance Creek Unit falls within this critical elevational range.

The aesthetic, recreational and economic values of a big game resource can be maintained at optimum levels through preservation of basic habitat, and through the annual, sustained-yield harvest of surplus populations. Since a great portion of Colorado's fall deer migrations occur prior to or during the state's general or "post" hunting seasons, the winter range areas play a major role in annual harvest programs. Suitable public access must be provided if game resources are to be properly utilized and deer herds maintained at population levels consistent with available habitat.

The boundaries of the Piceance Creek Basin shale resource area coincide directly with Colorado's Division of Game, Fish and Parks Game Management Unit No. 22. The value of this unit as a favored deer range and hunter use area is revealed through a review of annual game harvest statistics.

During a 9-year period between 1960 and 1969, an average of 6,001 deer were harvested annually from within the 650,000-acre unit. This key range, constituting approximately 1 percent of the Colorado area, has contributed up to 10 percent of the total deer harvest during some years.

Annual harvest totals in Unit 22 since 1957 have varied from a low of 2,408 in 1966 to a peak kill of nearly 12,000 animals in 1961. This variation, in large part, reflects the influence of management decisions designed to establish a favorable balance between deer populations and their habitat.

Over a 9-year period an average of 5,611 hunters participated annually in Unit 22 deer harvests. When using an assigned factor of 2.5 hunter days per sportsman's visit, deer harvests alone provide an average 15,000 recreational days use annually within the basin. To this total may be added the days of recreational participation by tourists and visitors who enjoy observing deer on winter habitat or witnessing the deer herd concentrations associated with spring deer migrations.

The importance of the Piceance Creek Basin game range resource is attested to by the Colorado Department's continuing efforts in its preservation, management, and maintenance. Throughout the past two decades this agency has acquired fee title ownership to more than 26,000 acres and cooperative resource management control over approximately 150,000 acres of key basin habitat; conducted a continuing and systematic series of game-range investigations; and has promoted the development of a road system for provision of public access. For many years this big game resource area, centered within the heart of the White River Plateau, has constituted the base for an important recreational enterprise, providing benefits for the nation's sportsmen, local ranchers, businessmen, and the general economy in surrounding communities.

Although the mule deer is of prime importance, populations of a number of other wildlife species are present within the basin, contributing to its aesthetic, recreational, and economic potential. Grouse, ducks, rabbits, lion, doves, chukars, and miscellaneous non-game species are normally present. Seasonal use by limited numbers of elk is not uncommon.

III. SITE SELECTION

3.1 METHOD.

The Memorandum of May 28, 1970 suggested that "proposed methods of development for typical areas be outlined and selected methods for mining and processing studied."

The model sites have been selected to illustrate, as nearly as possible, typical environmental situations. They are not in any way meant to signify that these might be actual lease sites. To the extent that the sites were not typical of the entire region, specific treatment of the ecological problems was to be developed on a regional basis.

Sites were selected to represent an underground mine site, a surface mine site, and an in situ site. The location of these sites is shown on Figure 3.1. Each hypothetical site contains 5,120 acres, the maximum acreage permitted by the Leasing Act of February 25, 1970.

Because there is no federal acreage available for lease which includes topography and geology characteristic of a canyon wall mine site, the Committee recommended that no attempt be made to describe such a mine and plant.

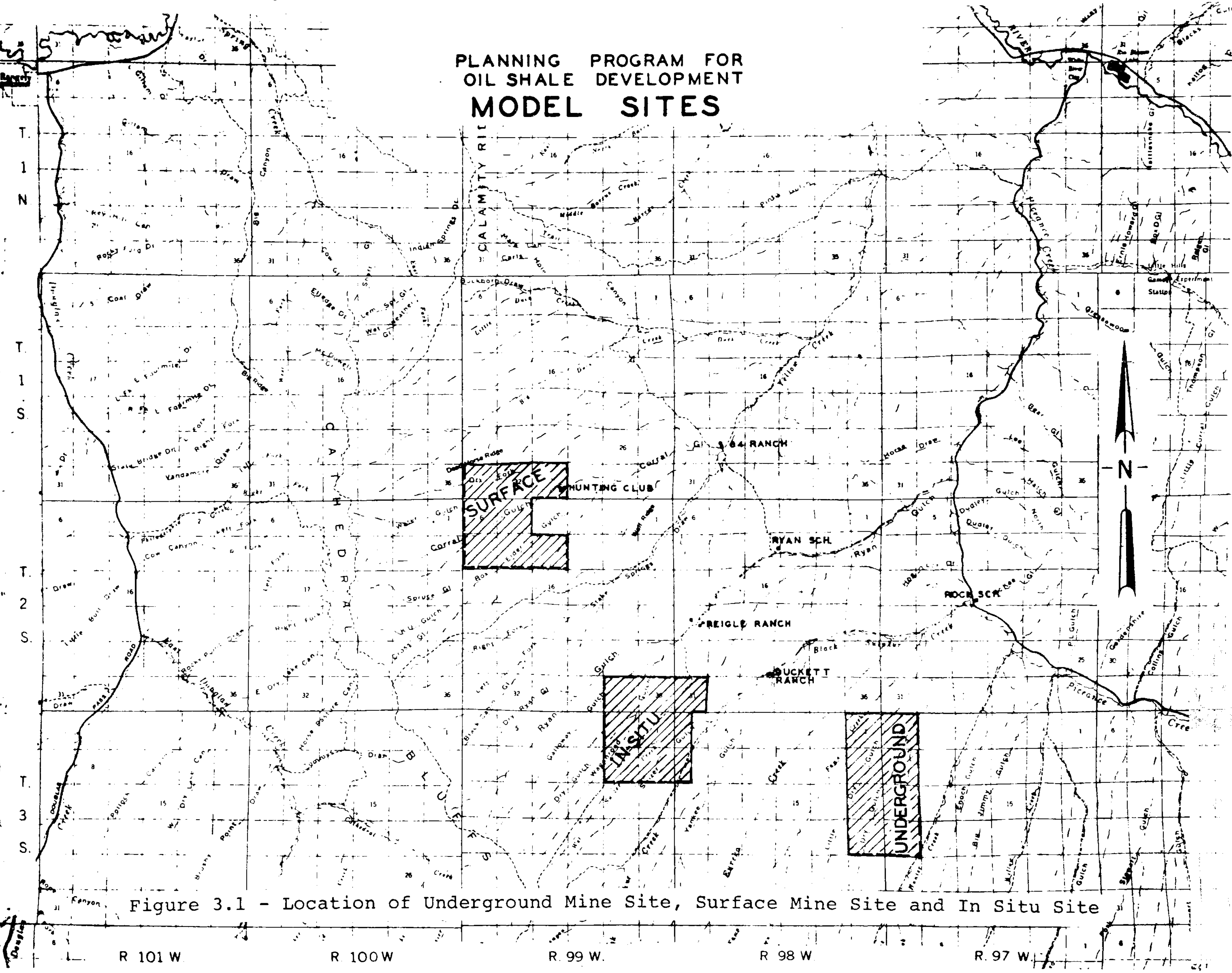


Figure 3.1 - Location of Underground Mine Site, Surface Mine Site and In Situ Site

3.2 UNDERGROUND MINE SITE.

The underground mine site is located in Township 3 South, Ranges 97 and 98 West, across broad ridges separating the drainages of Hunter Creek, Dry Gulch, Little Dry Gulch, and Fawn Creek. Maximum elevation on the highest point of the ridge at the south boundary of the site is 7,342 feet. The minimum elevation at the north boundary on the Fawn Creek bottom is 6,380 feet. Typical variations in altitude between stream bottom and ridge top are from 100 to 400 feet.

The topography is characterized by finger-like ridges separating long, straight valleys. From flat, wide stream beds, ridges rise sharply through steep, sometimes perpendicular, banks to gentle slopes forming the ridge tops. Pinon, juniper, sage brush, mountain mahogany and service berry predominate at higher elevations, while salt bush and greasewood mark the lower ridge slopes and valley growth.

Range conditions in the area vary from fair to poor, according to BLM classifications. The site is classified by the BLM in Scenic Category C, meaning "moderate variety in topography, vegetation, and/or water bodies." There are no running streams except during the spring run-offs and cloudbursts, nor are there springs, reservoirs or other water wells located on the site. The topography of the site is shown in a section of the U.S.G.S. Map, Rock School Quadrangle, 1:24000 (Figure 3.2), and a copy of the quadrangle is attached as Appendix 3.1. Aerial photograph of the site are attached as Appendix 3.2.

The principal agricultural use of the land on the site is the grazing of cattle during the fall, winter and spring. This site is included in grazing allotments which are licensed for a total of 8,210 A.U.M. (animal unit months) qualifications for spring, summer and fall grazing. The grazing capacity of the underground mine site has been estimated at 404.9 A.U.M., indicating that if the entire site were eliminated from grazing use, the allotments would lose about 5 percent of their grazing capacity.

An exhibit estimating the overburden on the Mahogany Ledge in the vicinity of the underground mine site and estimates of intervals of shale averaging more than 30 gallons per ton and the reserves of 30 gallons per ton shale is attached as Appendix 3.3.

3.3 SURFACE MINE SITE.

The location, geology and topography of the surface mine site is typical of several potential locations

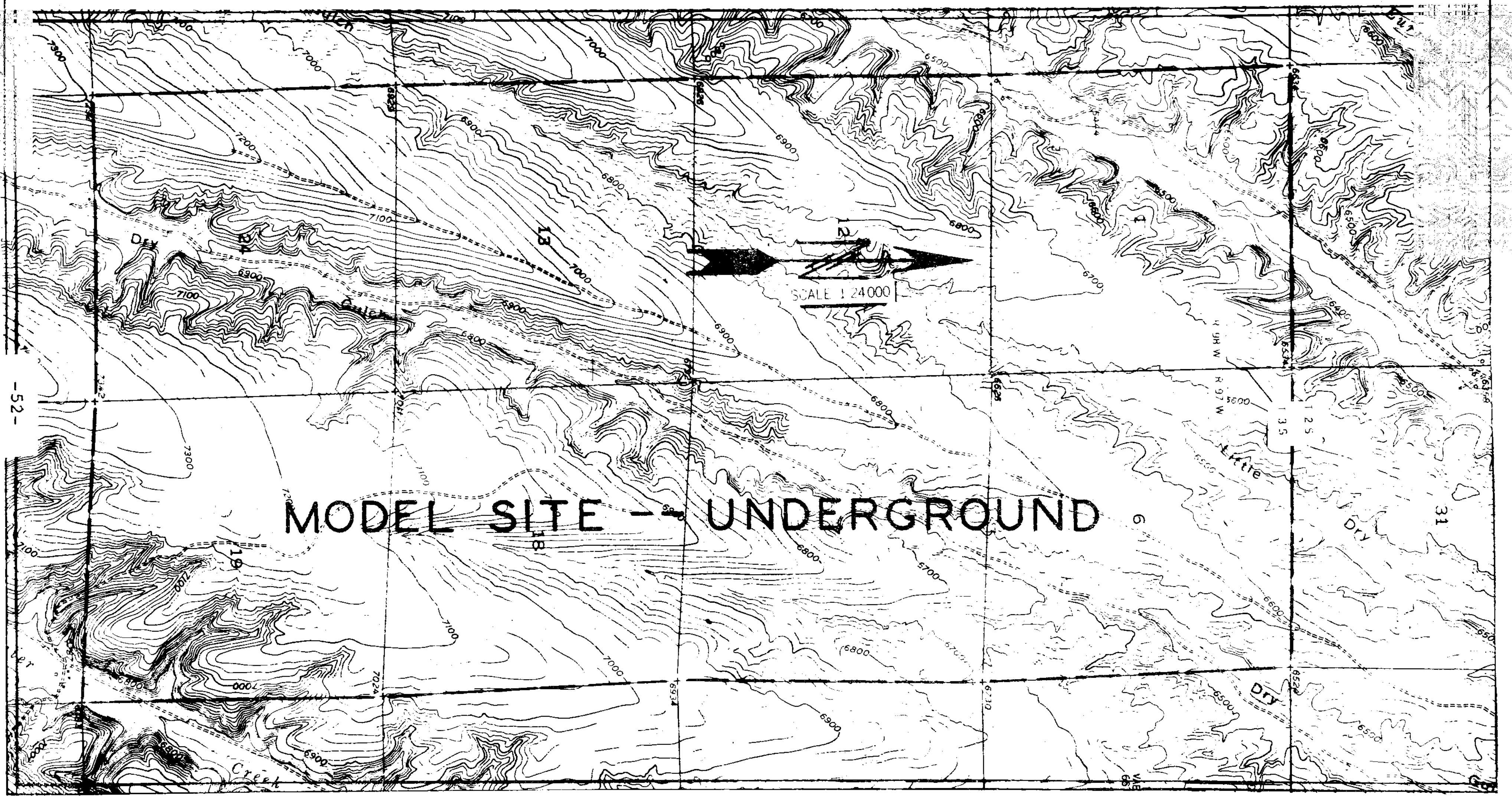


Figure 3.2 - Topography of Underground Mine Site

for surface mines in the area. The 5,120 acre site is approximately 18 air miles southeast of the town of Rangely, Colorado, and some 56 miles due north of Grand Junction. It covers all or portions of nine sections of land in Townships 1 and 2 South, Range 99 West.

Surface elevation varies from 6,750 feet on the east to 7,789 feet on the northwest corner; average elevation is 7,200 feet. The site is dissected west to east by alternating deep gulches and high ridges. Some 4-3/4 miles to the west, running generally north and south, are the Cathedral Bluffs, which have a ridge elevation of about 8,600 feet. Further west, a series of extremely rugged and moderately deep canyons run roughly perpendicular to the bluffs. These canyons drain into Douglas Creek, which flows from southeast to northwest some five miles west of the Cathedral Bluffs.

The Cathedral Bluffs mark the western limit of the Piceance Creek Basin and of the oil shale deposit in the basin. For many miles, the Mahogany Ledge, a rich oil shale bearing zone of the Parachute Creek Member of the Green River Formation, is exposed near the top of the bluffs. At the bluffs, the Mahogany Ledge is some 20 to

40 feet thick, while the upper oil shale zone is some 200 to 300 feet thick. To the east, the entire oil shale sequence increases in thickness. Across the model site, a zone averaging 25 gallons of oil per ton is 600 feet thick on the west, increasing to 1,000 feet on the east. At the model site, overburden on the Mahogany Ledge varies from 20 feet to 640 feet; the overburden to ore ratio rarely exceeds 1:1.

Range conditions in the area are classified as fair by the BLM. The western one-quarter of the site is classified in BLM Scenic Category B, meaning "excellent variety in topography, vegetation, and/or water bodies." The eastern three-quarters of the site is classified in Scenic Category C. There are no running streams on the site, but the U.S.G.S. maps indicate two springs on the site and the resource inventory prepared by the BLM indicates a water well on the site. The topography of the site is shown in a section of the U.S.G.S. Map, Sagebrush Hill, Colorado Quadrangle, 1:24000 (Figure 3.3) and a copy of the quadrangle is attached as Appendix 3.4.

Aerial photographs of the site are attached as Appendix 3.5.

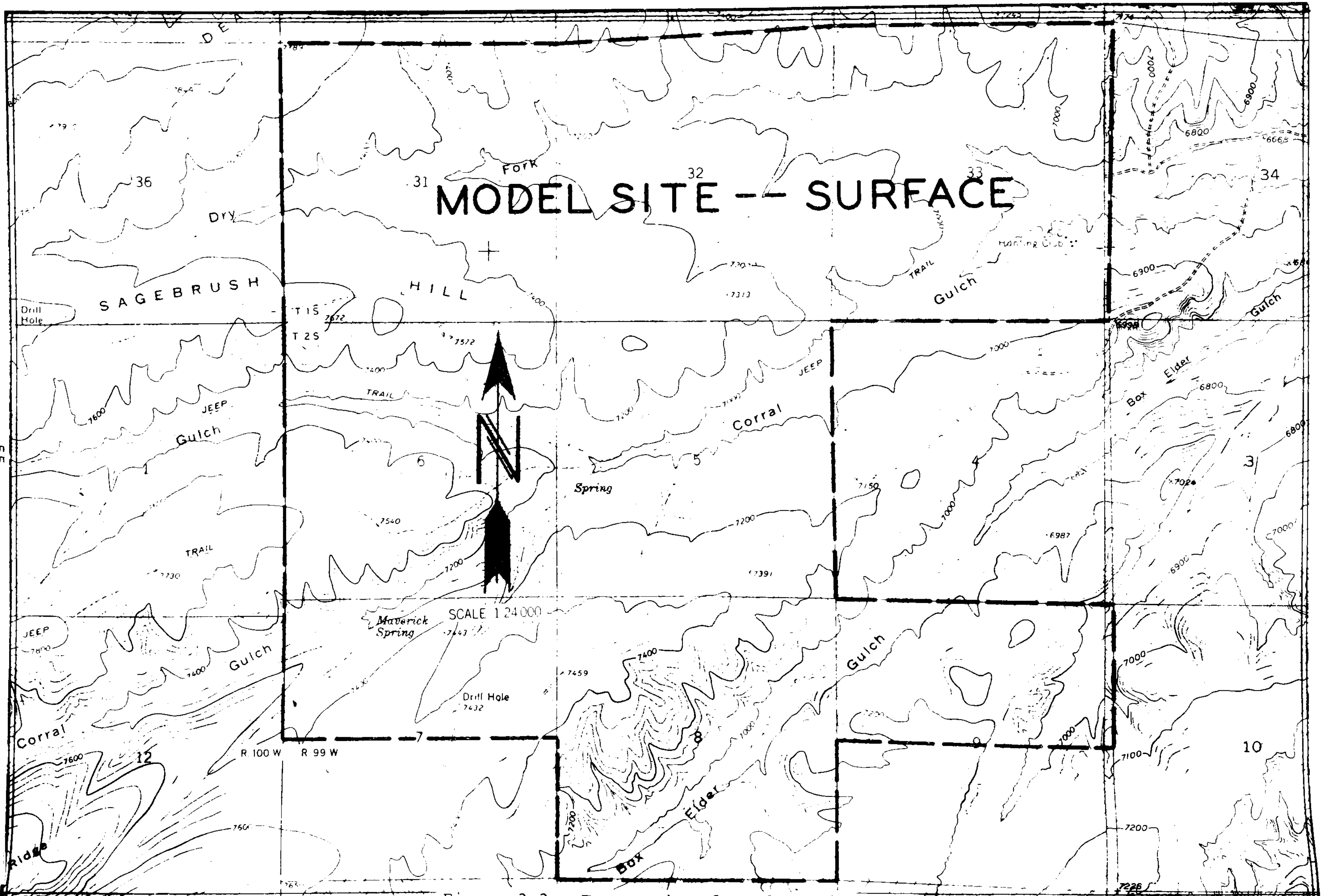


Figure 3.3 - Topography of Surface Mine Site

The principal agricultural use of the surface of the land included within the site is the grazing of cattle during the spring and summer. The southeast corner of the tract is included within the Box Elder Allotment; the balance of the site is included within the Square S Allotment System. These allotments have aggregate grazing capacity of 12,674 A.U.M.'s. An estimate of the grazing capacity of the site is 338 A.U.M.'s, indicating a grazing capacity loss of 2.7 percent if all of the surface of the site were withdrawn from grazing. However, more loss may result from interference with cattle migration routes than from loss of grazing capacity.

An exhibit estimating the overburden on the Mahogany Ledge in the vicinity of the surface mine site and an estimate of the intervals of shale averaging more than 25 gallons per ton and the reserves of 25 gallon per ton shale is attached as Appendix 3.6.

3.4 IN SITU SITE.

The in situ site is located in Townships 2 and 3 South, Ranges 98 and 99 West, across the broad ridges which separate the upper end of Black Sulphur Creek on the southeast from Swizer Gulch, Wet Swizer Creek, Wagonroad Gulch, and Galloway Gulch on the northwest. Maximum elevations on the highest point of the ridge at the southwest corner of the site is 7,720 feet. Minimum elevation on the north central boundary is 6,780 feet. Typical variations in altitude between the stream bottoms and ridge tops range from 400 feet at the southwest corner to 150 feet in the area of the north boundary of the site.

The topography is much like that of the underground mine site, with the same kinds of vegetation. Range conditions vary from poor in the area south and southwest of Wagonroad Ridge to fair in the area northwest of the ridge. The site is classified by the BLM in Scenic Category C. There are no running streams except Black Sulphur Creek, and except during spring runoffs and cloudbursts, there are no other streams, springs, reservoirs or water wells located on the site. The topography of the site is shown in a section of the U.S.G.S. Map, Yankee Gulch, Colorado Quadrangle, 1:24000 (Figure 3.4), and the quadrangle is attached as Appendix 3.7.

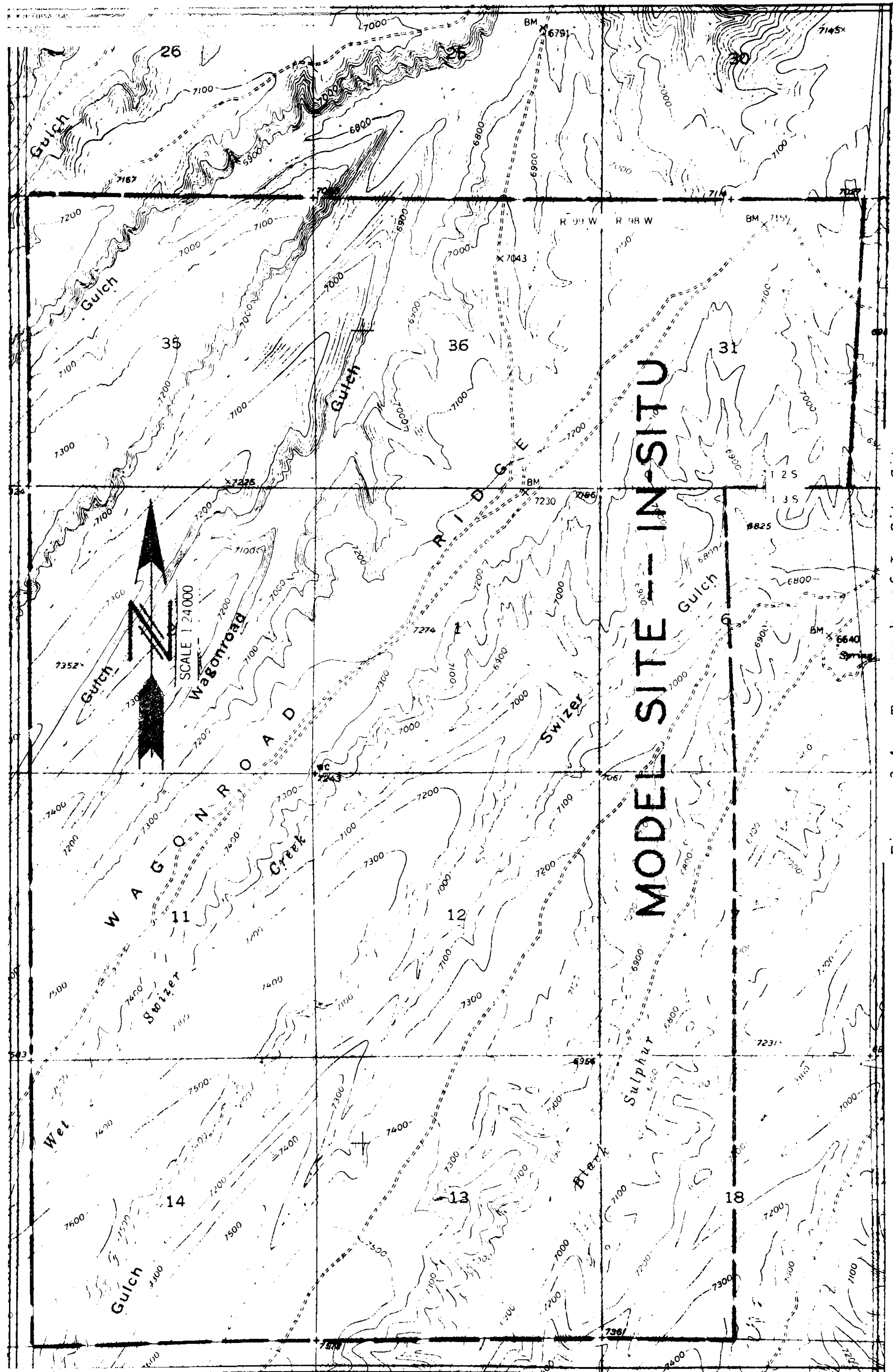


Figure 3.4 - Topography of In Situ Site

Aerial photograph of the site are attached as Appendix 3.8.

The principal agricultural use of the lands on the site is the grazing of livestock during the fall, winter and spring. The area south and east of the ridge separating Swizer Gulch and Wagonroad Ridge is included within the Square S Allotment Management Plan. The area north and west of that ridge is included within the Reagles Allotment Management Plan. A small portion of the site is included in the Black Sulphur Creek Allotment. These allotments have a total grazing capacity of 8,839 A.U.M.'s. The site is estimated to have a grazing capacity of 333 A.U.M.'s, indicating a maximum possible loss of 3.8 percent of the grazing capacity if all of the surface of the site is used for industrial purposes.

IV. UNDERGROUND MINING
AND SURFACE RETORTING

This chapter describes the industrial activities and environmental resources which will be involved if underground mining and surface retorting techniques are used to extract and upgrade shale oil. These techniques are treated in some detail because a full understanding of them is a necessary prerequisite to meaningful solution of the ecological questions presented.

The model underground mining site is appropriately located to raise two environmental issues unique to the Piceance Creek Basin: (1) the impact of mining and processing and related activities on the winter deer range, and (2) the effect of the saline water zone on mining and processing of oil shale. A discussion of these and other environmental factors, as well as detailed descriptions of the processing techniques, follows in the sections on Underground Mining Techniques, Surface Retorting, Solids Residue Disposal, Shale Oil Upgrading, and Associated Mineral Recovery.

4.1 UNDERGROUND MINING TECHNIQUES.

Underground mining techniques have been under nearly continuous study by the Bureau of Mines and industry since the commencement of mining at Anvil Points by the Bureau in 1944. All of the Bureau's field research in mining was terminated in 1956.

An excellent description of the basic techniques used by the Bureau of Mines at Anvil Points is contained in Bureau of Mines Bulletin 611 entitled "Oil Shale Mining, Rifle, Colorado, 1944-56" by J. H. East and E. D. Gardner. The basic techniques developed by the Bureau of Mines are valid today although equipment efficiencies and size have been improved as have drilling and blasting techniques.

From 1956 through May 1958, Union Oil Company of California conducted mining operations near the confluence of the East Fork and the Middle Fork of Parachute Creek.

From 1964 through 1967 the Colorado School of Mines Research Institute, as contractor for a group of six oil companies consisting of Continental Oil Company, Humble Oil and Refining Company, Mobil Oil Corporation, Pan American Petroleum Corporation, Phillips Petroleum Company, and Sinclair Research, Incorporated, conducted further mining operations at Anvil Points mine.

In 1965 Colony Development Company began mining operations in connection with its semi-works retort on the Middle Fork of Parachute Creek and such operations have continued intermittently since that date.

These efforts demonstrated the feasibility of the room-and-pillar method of mining oil shale. They resulted in the drifting of more than 10,000 lineal feet of tunnel and the mining of over 1.5 million tons of oil shale. The room-and-pillar method appears to be a viable method of mining shale from the model underground site in quantities of 60,000 tons per day; however, it is probably limited to room heights of not more than 100 feet. A cut-away perspective drawing of an underground room-and-pillar mine is shown in Figure 4.1. Other methods capable of mining thicker sections will unquestionably be developed

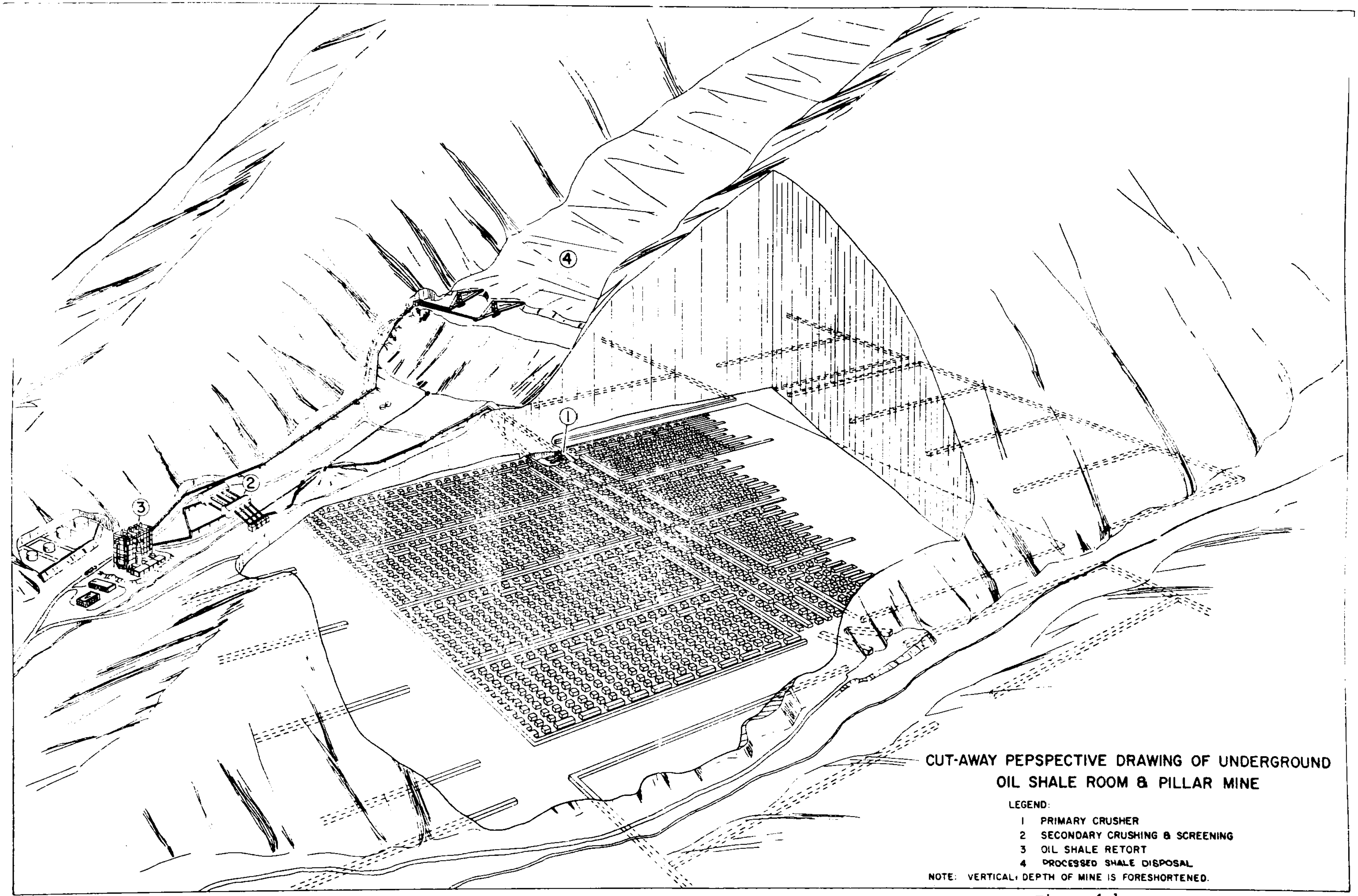

1
2
3
4
CUT-AWAY PEPSPECTIVE DRAWING OF UNDERGROUND
OIL SHALE ROOM & PILLAR MINE
LEGEND:
1 PRIMARY CRUSHER
2 SECONDARY CRUSHING & SCREENING
3 OIL SHALE RETORT
4 PROCESSED SHALE DISPOSAL
NOTE: VERTICAL DEPTH OF MINE IS FORESHORTENED.

Figure 4.1

as the need arises.

The volume of water encountered in mining will vary throughout the Piceance Creek Basin. Experience has shown that volumes are extremely small in the southern part of the basin and experimental mines in this area have remained relatively dry for many years. As described in other sections of this report, saline water is contained in the principal aquifer referred to as the leached zone of the Parachute Creek Member.

Although water may be encountered in sinking deep shafts through the leached zone, it is believed that the shafts can be grouted or cased to stop water encroachment. Saline water encountered in mining may be used in the disposal of processed shale, perhaps thereby minimizing or even eliminating any water disposal problems. Hydrology, water availability, and disposal are discussed in greater detail in other sections of this report.

For the purpose of this report it was assumed that a 100-foot section would be mined from the Mahogany

Ledge which lies between 800 and 1,200 feet below the surface of the model site. Other rich oil shale zones, which could be considered for mining, underlie the Mahogany Ledge. These zones contain associated minerals such as nahcolite and dawsonite; however, this area lies below the water-bearing leached zone and the water may present a problem in mining.

The amount of shale which can be removed without subsidence of the surface depends on the physical properties of the pillars and the amount of overburden. Assuming an average overburden of 1,000 feet and geologic characteristics based on limited cores, between 65 and 70 percent of the shale could be removed without significant surface effect. Percentage of extraction usually decreases as depth increases, but back filling with retort residue could possibly permit increased mine extraction with little or no effect on subsidence. These effects can be calculated once the physical properties of the shale are determined.

Although experimental mining work to date has involved only surface disposal of processed shale, research in waste disposal conducted by the Spokane Research Center of the U. S. Bureau of Mines and other laboratory work suggest that development of the mine in sections could permit the return of portions of the retort residue to those mined-out sections. Except possibly in the lower zone, which contains sodium minerals, all of the processed material cannot be returned to the mine for two reasons: (1) room is needed for ongoing mining operations, and (2) the volume of the residue exceeds the mined void. The Bureau study indicates that 90 percent of the open space in the mine is available and could be used for retort residue storage after mining operations cease.

Depending on the approach used and the amount of compaction, it has been estimated that 50 to 70 percent of the processed shale or retort ash could be returned to the mine. This subject is expanded in the "Solids Residue Disposal" section.

Based on the Bureau's calculations, 35 gallon per ton oil shale weighs 130 pounds per cubic foot in place and occupies 15 cubic feet per ton. The broken shale with an 8 inch maximum particle size (42 percent voids) weighs about 78 pounds per cubic foot and occupies about 26 cubic feet per ton.

4.2 SURFACE RETORTING.

Three surface retorting processes have been investigated in field operations in the United States in recent years. These are (1) the gas combustion retort developed by the Bureau of Mines, (2) the underfeed retort of Union Oil Company of California, and (3) the TOSCO retorting process now being tested by Colony Development Operation.

In all of these retorts, crushed oil shale is heated to decompose the solid organic material in the oil shale and to produce crude shale oil as a vapor, by-product gas, and retorted or processed shale. After heating to 900°F, oil shale is fully retorted and is free of organic material except for a carbon residue.

Heating is the only known commercially practical method for recovery of oil from the oil shale deposits of the Piceance Creek Basin. Solvent extraction, for example, is not satisfactory because the organic material in oil shale is at most only slightly soluble in any known solvent.

The following describes the three retorting processes and discusses environmental considerations in their operation. Also included is a discussion of the environmental factors in crushing oil shale, since all the retorting plants require crushed shale as feed.

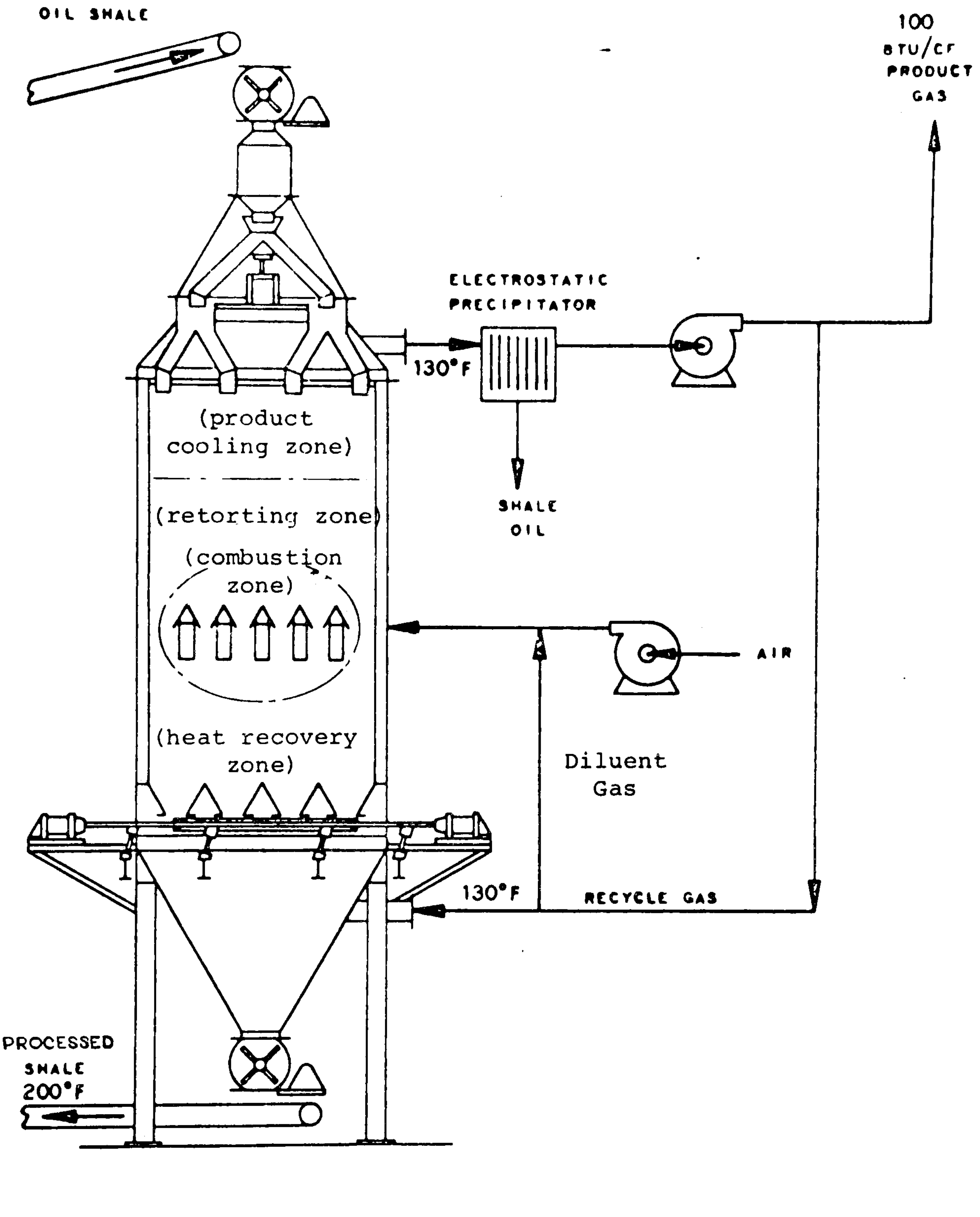
(a) Gas Combustion Process.

The gas combustion retorting process was developed by the U. S. Bureau of Mines between 1944 and 1955 at the Anvil Points Oil Shale Experiment Station at Rifle, Colorado. The investigation included operation of retorts with nominal capacities of 6, 25 and 150 tons per day. Also included in the Anvil Points program were experimental mining of oil shale by the room-and-pillar method, investigations of raw shale crushing and processed shale disposal, and testing of facilities for refining crude shale oil.

In 1964 to 1967, a two-stage evaluation of the process was undertaken at Anvil Points by The Colorado School of Mines Research Foundation and the six oil companies named earlier in Section 4.1 of this report. The first stage was evaluation of the retorting process at the scale of the existing equipment. The second stage was evaluation of scale-up factors for commercial scale retorting.

(1) Process Description. In the gas combustion process, as illustrated in Figure 4.2, shale flows through the retort by gravity and heat is supplied by direct gas-to-solids heat exchange and internal combustion. The retort is a vertical, refractory-lined shaft equipped with shale and gas handling devices. Shale flows downward through the retort countercurrent to a rising gas stream. The retort has four functional zones, although there is no physical separation and no exact dividing line between any of the zones.

Crushed and sized shale, generally with a maximum particle size of 2 to 3 inches, moves downward as a bed through the retort vessel, passing first through the product cooling zone within which it is heated almost to the retorting temperature (900°F) by rising gases from the retorting zone. It then flows downward through the retorting and combustion zones where it is heated to temperatures exceeding 1200°F.



GAS COMBUSTION PROCESS FOR RETORTING OIL SHALE

Figure 4.2

The sustaining heat for the process is produced in the combustion zone by burning part of the product gas plus some portion of the carbon residue left on the retorted shale. The retorted shale moves from the combustion zone down through the heat recovery zone. It is cooled there by transfer of heat to a rising stream of recycle gas. The cooled, processed shale is discharged from the retort mechanically at a controlled rate, which in turn governs the retort throughput.

Cool recycle gas, comprising predominantly hydrocarbons, carbon dioxide, and nitrogen, is injected at the bottom of the vessel and is heated as it rises through the processed shale in the heat recovery zone. Air, diluted with recycle gas, is admitted to the retort through a distribution device located near the center of the retort. This mixture is heated quickly by contact with processed shale, and oxygen in the mixture then burns combustibles in the gas stream and processed shale to produce hot flue gas. The flue gas and recycle gas mix and flow upward to the reactor, contacting the raw shale and heating it sufficiently to cause retorting.

The vapors formed in retorting mix with the rising gas stream and are cooled by the contact with raw shale in the product cooling zone. In the cooling process the crude shale oil vapor condenses as a fine mist or fog. The cooled gas and mist flow out the top of the retort and pass through separators to remove particulate matter and to disengage mist from the gas stream. After the separation steps, the oil-lean gas is compressed and recycled to the retort or discharged as product.

The products from the gas combustion retort are crude shale oil, by-product gas, and processed shale.

The crude shale oil typically has a gravity of 20°API, a pour point of 90°F, and contains 2 weight percent nitrogen and 0.65 weight percent sulfur.

The by-product gas is a combination of the products formed in the combustion zone, vaporized moisture, and gaseous compounds formed by the retorting reaction. A typical gas analysis is shown below:

Typical Product Gas Constituents (Vol. %)

Carbon dioxide	23.7
Illuminants	1.0
Oxygen	0.2
Carbon monoxide	2.3
Hydrogen	5.7
Methane	3.4
Ethane	0.9
Nitrogen	60.2
Water	1.7

This gas has a net heating value of about 100 Btu/SCF and is produced at a rate in excess of 6,000 cubic feet for each ton of average grade shale charged to the retort. Because of its low heating value, this gas cannot be economically transported a substantial distance; however, it is of value in the plant vicinity. Commercial considerations of the gas combustion process generally envision the product gas being used as fuel for power and process steam generation.

The processed shale discharged from the gas combustion retort amounts to 75 to 80 percent of the weight of the raw shale feed. It is a soft, dry, friable rock of 2- to 3-inch maximum size and contains 2 to 3 percent organic carbonaceous matter. The bulk density is in the range of 60 to 80 pounds per cubic foot. It exits the retort at a temperature in the range of 175°F to 250°F. The processed shale contains little of the carbon residue formed in retorting because this material is partially burned as a process heat source. In the burning, the processed shale is heated above 1200°F and a large portion of the mineral carbonates in the shale are decomposed to mineral oxides.

(2) Air Quality. Air quality control considerations with the gas combustion retort are minor, because no gaseous effluents are discharged directly from the retort unit to the atmosphere. Control equipment in the retort unit would be limited to standard dust collection systems where needed to restrict particulate emissions at open solids transfer points.

The combustion of by-product gas for power or steam generation will result in discharge of flue gas to the atmosphere. The by-product gas is expected to be low in sulfur content and particulate matter.

Special emission control equipment is thus not expected to be required in a power plant using this gas.

(3) Water Quality. At times the Bureau of Mines researchers operated the gas combustion retorts so that water condensed out of the gas stream in the oil recovery equipment. However, the difficulty inherent in separating the dust-laden retort water from the product oil caused the researchers to conclude that the retort off-gas temperature should be maintained sufficiently above the dew point of the contained water to preclude condensation with the product oil. Thus it can be expected that commercial operation of a gas combustion retort would result in formation of little, if any, liquid phase water. If water is formed, it will be necessary to investigate techniques for removing contaminants from the water. The techniques investigated would likely be those now in use to purify water that has been in contact with oil in conventional oil refineries.

Operation of power plants often includes return of water to rivers and streams. The water returned is generally warm and high in dissolved solids content. In power plants built near oil shale processing plants, return of water to rivers or streams can be avoided by using the water in the processed shale disposal operation.

(4) Water Conservation. There is no consumptive use of water in the gas combustion retort itself. The water consumed in the associated power generation plant will depend on the design of the facility. If necessary, water consumption can be substantially reduced by transfer of all process heat to air rather than water.

In all surface retorting processes, water is required for processed shale disposal. This use of water is discussed later in this report.

(5) Resource Utilization. The Bureau of Mines has shown that good oil recovery efficiencies can be achieved with the gas combustion retort. The yield was about 95 volume percent of Fischer Assay with the 6 ton per day retort and about 86 percent for the 150 ton per day retort. The process is thermally self-sufficient and,

as earlier noted, produces by-product gas suitable for power generation in the vicinity of the retort.

The gas combustion retort is preferably operated with a crushed shale feed that is relatively free of fine particles. The feed is thus screened to remove fines formed in crushing. The fine particles can be briquetted and then fed to the gas combustion retort or can be used as feed for a retort which is tolerant of fines.

(6) Land Requirement. The retorting units for a gas combustion retorting plant processing 60,000 tons per day of raw shale would occupy approximately 25 acres, including land needed for storage of sized shale feed.

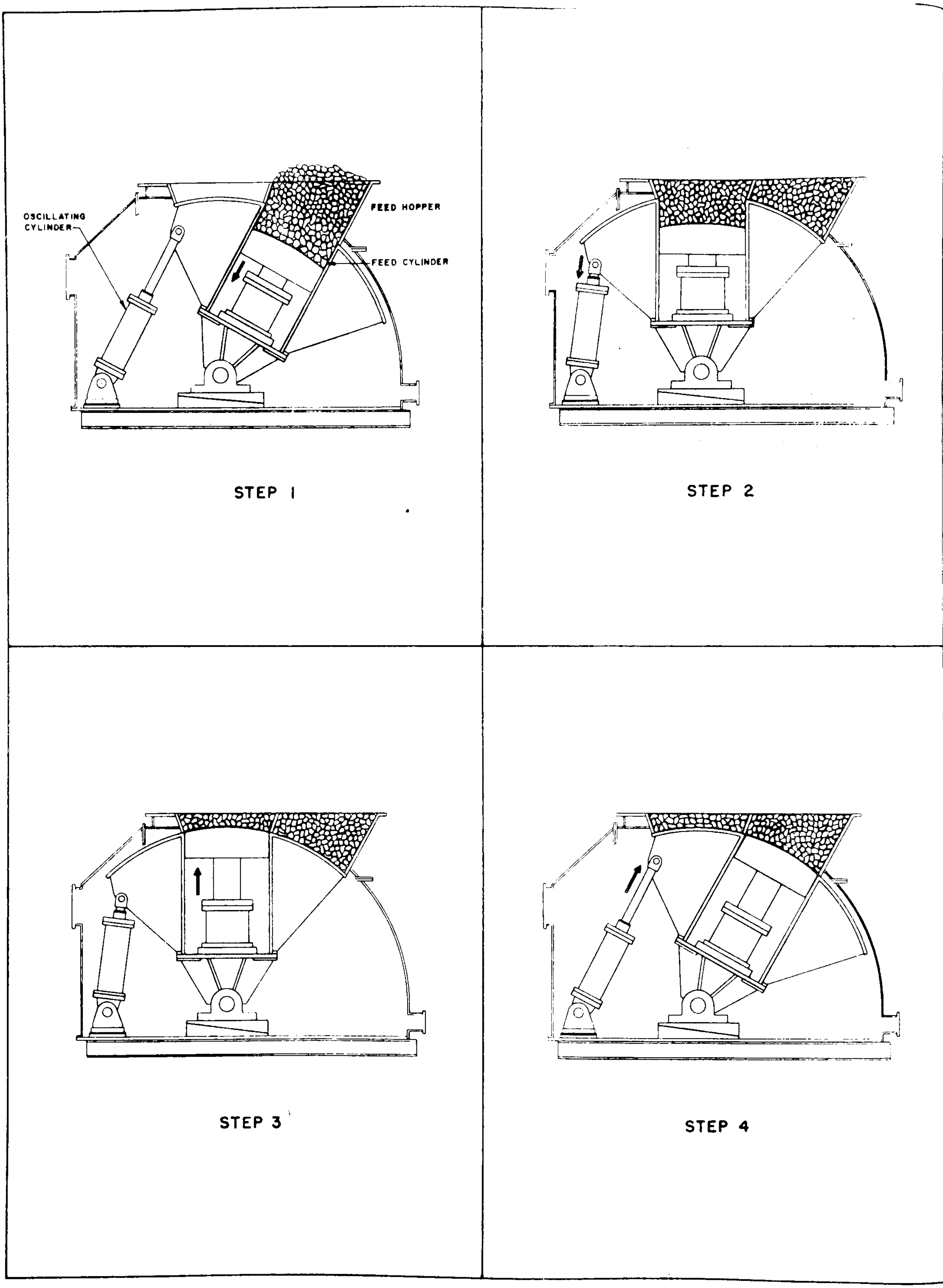
(b) Union Oil Underfeed Retort.

Pilot plant development of the underfeed retorting process began in 1948 at research facilities of the Union Oil Company of California. Field testing of the process was carried out in 1955 to 1958, at a site on Parachute Creek about 12 miles north of Grand Valley, Colorado. The field operation included mining of oil shale by the room-and-pillar method, crushing, retorting, and disposal of processed shale. The retort was operated at rates up to 1,200 tons per day.

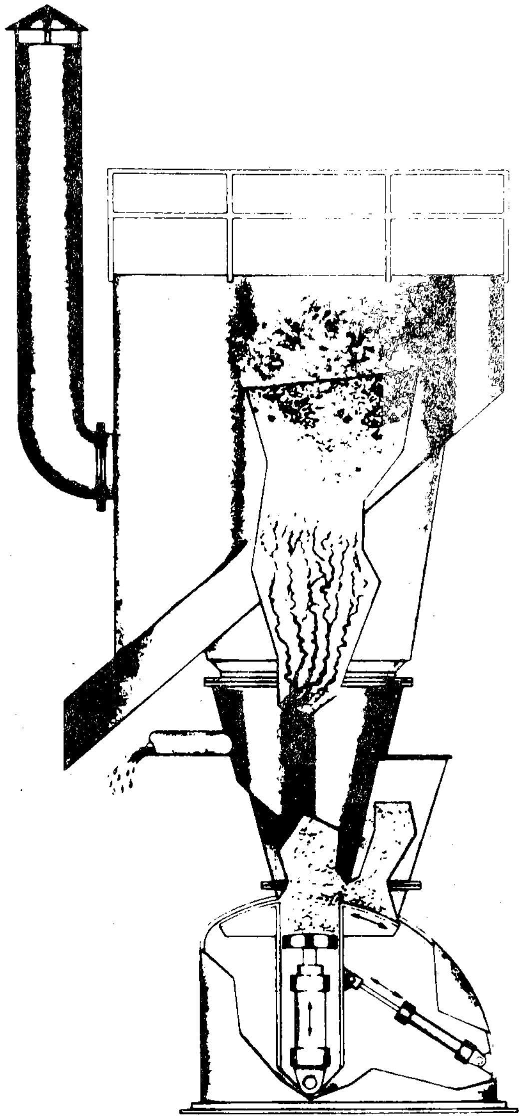
(1) Process Description. In the Union Oil retort, as in the Bureau of Mines gas combustion retort, air flows into the retort and heat is supplied by combustion reactions inside the retort. Also, in both processes, the retort vapor is cooled in the retort and shale oil is condensed and produced as a liquid.

A unique feature of the Union retort is the "rock pump" used to push raw shale into the bottom of the retort and upward through the retort. The operating principle of the rock pump is shown in the attached Figure 4.3. In Step 1, the rock pump takes a charge of shale and then swings over to the pumping position shown in Step 2. The shale is pumped into the retort (Step 3) and the pump then swings back for another charge of shale as shown in Step 4.

The complete underfeed retort is depicted in Figure 4.4. As the oil shale rock is pumped upward, it is first preheated by contact with hot gas flowing downward. Above the preheat zone, the rock is



UNION RETORT ROCK PUMP
Figure 4.3



UNION OIL SHALE RETORT

Figure 4.4

retorted, and on travelling further upward it enters a combustion zone in which carbon residue is burned off the retorted shale. The burned, retorted shale, in the form of a clinkered ash, continues upward and spills over a disposal chute at the top of the retort. It is cooled by cold air drawn up the chute and into the top of the retort.

The air flow is controlled by blowers which pull gas through the retort. The entering air, after being preheated by the clinkered ash, flows down into the combustion zone where burning reactions consume the oxygen in the air and provide heat for preheating and retorting the shale.

The vapor produced by retorting mixes with the gas from the combustion zone. The mixed gas flows downward and is cooled by direct contact with the entering raw shale. The cooled gas and condensed shale oil are separated in the bottom of the retort. The gas flows to a blower and is compressed for use as fuel.

The crude shale oil produced in the Union retorting process typically has a gravity of 21°API, a pour point of 90°F, and contains 2.0 weight percent nitrogen and 0.75 weight percent sulfur.

Like the Bureau of Mines gas combustion retort, the Union retort produces a low BTU by-product fuel gas. The gas has a heating value of about 120 BTU/SCF and is useful for generation of steam and power near the retort.

Processed shale discharged from the Union retort amounts to 65 percent of the raw shale feed, with most of it smaller in size than 10 inches. The bulk density is approximately 70 pounds per cubic foot. It is similar in chemical composition to processed shale from the Bureau's gas combustion process. Both materials are low in organic carbon content and in mineral carbonates.

(2) Environmental Factors. The Union Oil retort is excellent with respect to air and water quality control and water conservation. No gaseous effluents are discharged from the retort and, except for processed shale cooling and disposal, there is no consumptive use of water. Impure water produced in the process and requiring treatment is, as in the gas combustion process, low in quantity.

As with the Bureau of Mines' gas combustion process, a plant employing the Union Oil retorting process would likely include an associated power generation plant for utilization of the by-product gas from retorting. This fuel gas is free of particulate matter and contains only a small amount of hydrogen sulfide (0.3 volume percent or less). The sulfur dioxide generated in burning this gas would result in a concentration in the flue gas of about 125 ppm (by volume), well below proposed Colorado standards.

The Union retort requires no external heat and has demonstrated an oil recovery of 75 to 85 volume percent of Fischer Assay in large scale field operation. The retort has a high tolerance for fine particles, although a small percentage of the feed must be removed and disposed of with processed shale or used elsewhere.

A commercial plant producing 50,000 barrels per day of oil will require a 10-acre site for the retorting units.

(c) TOSCO Retorting Process.

Development of the TOSCO retorting process began in 1957 in pilot plant facilities of The Oil Shale

Corporation (TOSCO) located near Denver, Colorado. Field testing of the process was started in 1965 by Colony Development Company, as agent for Sohio Petroleum Company, Cleveland-Cliffs Iron Company, and TOSCO. The testing was done in a semi-works plant located on Parachute Creek several miles north of the site of the Union Oil Company field operation. Operation of the plant continued for over two years, until the end of 1967.

Early in 1969 Atlantic Richfield Company joined the original venture participants and became operator for the four party joint venture now known as Colony Development Operation. Information developed during the earlier operating period provided the basis for further field testing, which is just now beginning. The immediate objectives of the field program and other venture activity are to establish the technology for commercial processing of oil shale, including environmental safeguards, and to evaluate the economic feasibility of such a commercial operation.

The semi-works plant includes an underground room-and-pillar mine, a conventional crushing plant, a retorting plant designed to process 1,000 tons per day of raw shale, a processed shale disposal system, and facilities for cooling and condensing the shale oil vapor produced by retorting. The semi-works plant does not include facilities for upgrading crude shale oil. Conventional processes are used for this purpose and the required design and operating information is readily obtained in small scale testing.

(1) Process Description. Figure 4.5 illustrates the TOSCO retorting process. The heart of the process is the retort, a slowly rotating horizontal drum into which preheated crushed oil shale and heated ceramic balls are introduced. The rotation of the drum causes mixing of the materials and rapid transfer of heat from the balls to the shale. The flow rates and temperatures of the balls and shale are controlled to heat the shale to about 900°F, at which temperature the retorting reaction is rapid. The products from the retort are cooled balls, pyrolysis vapor, and processed shale.

The cooled balls are transported from the retort to the ball heater where they are reheated before

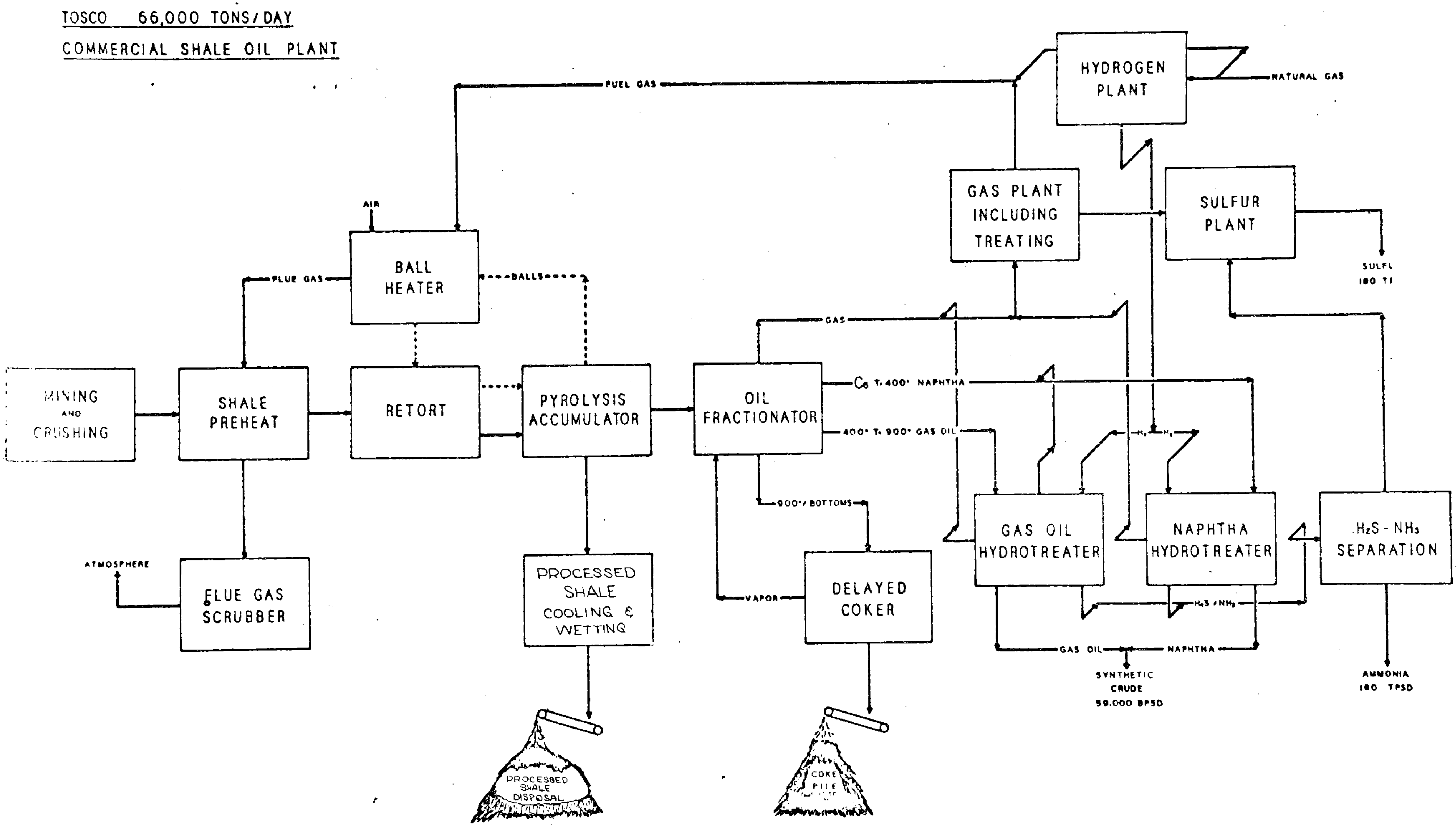

TOSCO 66,000 TONS/DAY
COMMERCIAL SHALE OIL PLANT
MINING AND CRUSHING
SHALE PREHEAT
FLUE GAS
FLUE GAS SCRUBBER
ATMOSPHERE
AIR
BALL HEATER
BALLS
RETORT
PYROLYSIS ACCUMULATOR
PROCESSED SHALE COOLING & WETTING
PROCESSED SHALE DISPOSAL
FUEL GAS
OIL FRACTIONATOR
GAS
C5 T. 400° NAPHTHA
400° T. 900° GAS OIL
900°+ BOTTOMS
VAPOR
DELAYED COKER
COKE PILE
HYDROGEN PLANT
NATURAL GAS
GAS PLANT INCLUDING TREATING
SULFUR PLANT
H2
GAS OIL HYDROTREATER
NAPHTHA HYDROTREATER
H2S-NH3 SEPARATION
H2S / NH3
GAS OIL
NAPHTHA
SYNTHETIC CRUDE 59,000 BPSD
AMMONIA 180 TPSD

Figure 4.5

flowing again to the retort. Heating is achieved in the ball heater by burning fuel and causing the resulting flue gas to flow through a moving ball bed in the heater.

The cooled flue gas leaving the ball heater is used to preheat raw shale by direct contact in a lift pipe system. The flue gas and shale enter the bottom of the lift pipe and both flow upward in the pipe. The shale is heated by transfer of heat from the gas to the shale. At the top of the pipe the gas and shale are separated, and the preheated shale then flows to the retort.

The pyrolysis vapor formed in the retort contains hydrocarbon gases and vaporized shale oil, as well as small amounts of steam, hydrogen sulfide, and other components. This vapor flows to conventional fractionation facilities in which it is cooled and partially condensed to form liquid shale oil streams of several different boiling ranges, condensed impure water, and gas.

In one configuration of a commercial plant the gas would be further processed in facilities which include compression and fractionation to remove gasoline range components. Facilities to remove hydrogen sulfide from the gas and convert it to elemental sulfur would also be included. The products from gas processing would then be sulfur free gas, additional shale oil liquid, and by-product sulfur.

In the TOSCO process the retorting is carried out in the absence of air and inert diluents except for a small amount of steam. Thus the fuel gas produced as described above is of high quality and suitable for use as plant fuel or for generation of hydrogen for oil upgrading.

The oil produced by the TOSCO retorting process is nearly identical to that produced by Fischer Assay, except that the gas processing steps described above recover light hydrocarbons (butanes and other gasoline boiling range materials) that are lost in Fischer Assay. The total oil produced (butane and heavier material) has a gravity of 26°API, and contains 1.7 percent nitrogen and 0.8 percent sulfur.

When retorting oil shale with a Fischer Assay grade of 36 gallons per ton, the processed shale formed is 81 weight percent of the raw shale feed. The processed shale from the TOSCO retort is substantially the same in chemical composition as that produced by Fischer Assay. It is virtually free of recoverable oil, and contains a carbon residue plus the inorganic material present in the raw shale. The inorganic material is largely unchanged by retorting except for dehydration and the modest amount of carbonate decomposition which occurs below 900°F. All of the processed shale is finer than 1/2 inch, with some 65 weight percent of it finer than 80 mesh. The material has a bulk density of about 70 pounds per cubic foot.

(2) Air Quality. The major air quality control consideration with respect to the retorting process is the discharge of ball heater flue gas to the atmosphere. As previously noted, the flue gas is first used to heat ceramic balls and then to preheat crushed shale before discharge to the atmosphere. As originally constructed, the semi-works plant was equipped only with cyclone separators to remove entrained raw shale particles from the flue gas. Past operation of the plant showed that

cyclone separators of the type tested did not sufficiently control particulate emissions. Operation also provided data on the quantity and size of the particles remaining in the flue gas. Based on these data, a wet scrubber was designed and tested in the pilot plant for removal of particulate matter by direct contact with water sprays.

After successful pilot plant scrubber tests, a wet scrubber has been installed in the semi-works plant for large scale testing in the forthcoming operating program. The water discharged from the wet scrubber will flow to a settler to concentrate solids, and the concentrate will then be combined with processed shale for disposal. The cost of the flue gas scrubber system for a 60,000 ton per day commercial plant has been estimated at $860,000.

The semi-works plant program will include stack emission measurement of sulfur oxides, nitrogen oxides, particulates and other components in the flue gas. These measurements will be made when burning unrefined shale oil, which is a low-sulfur fuel oil. Additional tests will be conducted burning alternate fuels.

There are several additional possible minor dust emission points. Appropriate equipment has been installed to control each of these.

(3) Water Quality. There are two water effluents from the TOSCO retorting process. One is from the wet scrubber and is a slurry of fine raw shale particles in water. The other is water formed during condensation of the retort vapor.

In the operation of the semi-works plant, tests will be carried out in which the slurry from the wet scrubber is mixed with processed shale for disposal. It is expected, from pilot plant experience, that this method of operation will be satisfactory. The test program will, however, include analysis of all produced waters.

Work is in progress to determine the optimum method for treatment of the water produced in retorting. The water contains soluble organic compounds extracted from shale oil naphtha. The types and amounts of the impurities present have already been determined, and are much the same as those in conventional oil refinery "sour" water streams. The treatment methods being considered are those which will purify the water sufficiently for use in the disposal of processed shale. These methods include steam distillation, reaction with chemical treating agents, and other techniques successfully practiced in conventional oil refineries.

(4) Water Conservation. Water is both produced and consumed in the retorting section. The net effect, calculated for a 60,000 ton per day commercial plant, is a water consumption in the retorting plant of less than one cubic foot per second, providing water consumption for process cooling is avoided. This does not include water consumed in other portions of the operation, such as mining, crushing, processed shale treatment, and oil upgrading. These additional requirements are discussed elsewhere in this report.

Total water consumption for a 60,000 ton per day commercial operation has been estimated at about 8 to 12 cubic feet per second, again providing that water use for process cooling is minimized.

(5) Resource Utilization. As has been stated, except for differences in gas condensation and processing techniques, the yields of liquid and gas are nearly identical for the TOSCO retort and for Fischer Assay. As also noted earlier, a commercial plant using the TOSCO process will likely include gas compression and fractionation facilities to condense butane and gasoline range hydrocarbons. Thus the yield of liquid product will be greater than in Fischer Assay and the production of gas will be lower. The liquid yield is in the range of 105 to 108 volume percent of Fischer Assay.

The gas produced in the TOSCO process can supply most of the heat required for retorting. When processing 36 gallon per ton shale, this gas provides 80 percent of the heat demand. The remaining 20 percent can be supplied by burning purchased natural gas, or alternatively, some three percent of the oil product.

Fine particles are acceptable feed for the TOSCO retort and the feed is thus not classified to eliminate fines.

(6) Land Requirement. An area of 100 acres or less is needed for the surface facilities of a 60,000 ton per day oil shale processing operation, exclusive of land use for processed shale disposal. The 100 acres includes crushing, crushed shale storage, retorting, oil upgrading, oil storage, and related parking, office and shop facilities. The retorting plant itself occupies less than five acres of this total.

(d) Crushing of Oil Shale.

In underground mining of oil shale by the room-and-pillar method, much of the shale is in the form of large boulders. All three of the field retorting operations previously described included operation of conventional crushing and screening equipment to produce retort feed of a suitable size composition.

The only significant environmental factor in crushing oil shale, as in most crushing operations, is particulate emissions. There are no liquid or gaseous effluents generated in the crushing.

Particulate emissions in crushing plants are conventionally controlled by water sprays, dust collection, enclosing the plant, filtering and scrubbing the air flow out of the enclosure, or, more likely, a combination of these. The enclosure and attendant air cleaning system can and should be adequately designed to protect the ambient air. Dust suppression and collection are used to provide good working conditions within the enclosure.

Dust suppression by water sprays is both effective and economic. The water required is in the range of 1.0 to 1.5 weight percent of the shale crushed, or about 0.2 to 0.3 cubic feet per second for a 60,000 ton per day plant.

4.3 SOLIDS RESIDUE DISPOSAL FOR UNDERGROUND MINE.

(a) Introduction.

The solids residue from an oil shale retort can be classified into two distinct types, depending on the retorting process. The direct heating processes developed at Anvil Points and by Union Oil Company of California produce a residue which has been contacted with air and burned, and which, for this discussion, will be called "retort ash." The indirect heating process developed by TOSCO and being tested by Colony Development Operation produces an unburned residue which in this discussion will be called "processed shale." Further descriptions of the two types of residue are given in the "Surface Retorting" section of this report.

Either residue can be disposed of in a moistened condition or as a water slurry. Selection of the disposal method depends on the type of disposal area (surface fill or an underground mine) and on the availability of water.

This section of the report discusses the aspects of solids residue disposal from a surface retort at an underground mine site. Discussions relating to disposal of retort residue from a surface mine operation are related to overburden and lean shale disposal, so are included in a separate section.

(b) Retort Ash Disposal.

The purpose of this section of the report is to outline the methods and to estimate the cost of disposing of processed ash from a direct heating retort supplied by a typical deep, underground mine and to examine the disposal of the retort ash by surface placement and/or by placing it back in the mine. Surface disposal is based on field tests by Union Oil Company of California and underground disposal is based on U. S. Bureau of Mines data.

(1) <u>Surface Disposal of Retort Ash</u>. The disposability of the retort ash produced by the underground feed retort was tested by Union Oil Company of California in demonstration operations. A disposal area was prepared and approximately 100,000 tons of ash were hauled to the area by truck as it was produced from the demonstration retort. After leveling and compacting the material in place with a D-7 Cat, it was allowed to weather a few years and was planted with native grasses. By irrigating and applying fertilizer, a grass cover was developed, suggesting that suitable techniques can be worked out for revegetating retort ash. Recent photographs of the Union disposal area are attached as Appendix 4.1.

The suitability of this residue for revegetation is supported by test results on a sample which was sent to the Colorado State University Soil Testing Laboratory. Results were as follows:

Sample Identification	No. 4068, 5/31/66
pH paste	8.5
pH 1:5	8.6
Conductivity (salts) mmhos/cm	4.0
Lime, %	19.8
Organic matter, %	1.1
Phosphorous, lb P_5O_5, Acre 6 in.	27
Potash, lb K_2O, Acre 6 in.	1000+
Zinc, ppm	17.5
SAR	3.1
Gypsum, Meq/100g.	12.0
Texture	Sandy Loam

This material does not appear to pose a serious problem in establishing vegetation. It is not excessively high in salt, and it would appear that grasses and browse could establish themselves. The material is very low in phosphorous. An application of P_2O_5 at a rate of 100 lbs/acre may be desirable.

Tests which were made simulating percolation of natural stream flow through a bed of ash indicated that the effluent pH and total dissolved solids (TDS) increased at the start an incremental amount depending on the length of flow channel. Thereafter, the effluent pH and TDS leveled off and tended to approach natural stream flow characteristics. For this reason, it is recommended that culverts or canals be installed to carry existing streams under or around any proposed ash disposal area. Other tests simulating normal precipitation over the disposal area showed that the waters normally soaked in or evaporated and sublimed and would not become part of the surface runoff.

(2) Underground Disposal of Retort Ash. On the basis of the assumptions discussed under "Underground Mining Techniques," the mining of 60,000 tons will create a void of 900,000 cubic feet per day. The retort ash will weigh approximately 54,000 tons (90% of raw shale weight) and occupy about 1,215,000 cubic feet. Studies conducted by the Spokane Research Center of the Bureau of Mines indicate that 80 percent of the residue can be placed underground. On this basis there will be approximately 243,000 cubic feet, or approximately 10,700 tons of shale residue daily which must be stored on the surface. If a slurry method is used, the residue

from a gas combustion retorting process would probably be crushed, slurried, and pumped underground at 50 percent solids. After a reasonable time this material should dewater to 70-80 percent solids and be relatively stable.

The cost for placing retort ash back in the mine varies widely between studies, but on the average, according to a Bureau of Mines study conducted at the Spokane Research Center, the costs for disposing of slurried residue run from 13 to 17 cents per ton direct costs, excluding capital expenditures of between 3 and 4 million dollars. Costs for surface emplacement by the slurry method range between 3 and 6 cents per ton excluding capital expenditures. These figures come from mining operations other than oil shale and do not include any additional costs which will be incurred to drain and stabilize the pile. If the slurry method is not applicable, placement costs for both above ground and below ground would be considerably greater. It is estimated that 30 percent of the disposal costs can be allocated to environmental protection.

Pumping a slurry of retort ash as mentioned above at 50 percent solids with 70 to 80 percent recycle would consume approximately 4 to 6 cubic feet of water per second for a plant capable of processing 60,000 tons per day.

(c) <u>Processed Shale Disposal - TOSCO Process</u>.

The crude shale oil, gas and water produced in retorting 36 gallon per ton oil shale in a TOSCO retort account for 19 weight percent of the raw shale fed into the retort. The remaining 81 percent of the feed is removed from the retort as processed shale. Since commercial oil shale plants are envisioned to be of a size of 60,000 tons per day or more, the disposal of the large volume of processed shale merits careful consideration, not only to avoid degrading the environment, but also to achieve, if possible, an improvement in overall environmental values. The disposal plan should be integrated into an overall land use plan which considers broad functional values including, for example, wildlife support. As explained below, much has already been accomplished toward development of a satisfactory disposal procedure, and a detailed program is in progress to extend the development.

(1) Chemical Composition. The processed shale formed in the TOSCO retort is substantially the same in chemical composition as that produced by Fischer Assay, is virtually free of recoverable oil, and contains some organic carbon residue plus the inorganic material present in the raw shale. The inorganic material is largely unchanged by retorting except for dehydration and the modest amount of mineral carbonate decomposition which occurs below 900°F.

Because mineral carbonate decomposition in the TOSCO retorting process is minor, the process is very similar to the natural weathering process in its effect. Thus the inorganic material of the processed shale is similar in composition to the local soil of the site area. Both the local soil and processed shale can be characterized as young, sterile, alkaline soils devoid of most plant nutrients.

Leaching tests with processed shale and with the local soil confirm the similar composition of these materials. Leaching the two materials with water removes the same components from each, with increased amounts in the case of processed shale which has not been previously contacted with water. The components extracted are principally calcium, sodium, magnesium and sulfate.

(2) Physical Characteristics. Raw shale is comprised of fine grained particles bound together by the organic material, or kerogen, which is the source of shale oil. Retorting removes most of the organic material and causes the shale to lose much of its physical strength and thus size reduction occurs during retorting. Using the TOSCO retort, some 65 percent of the processed shale is finer than 80 mesh.

Dry processed shale is difficult to handle in a disposal operation. Compaction of the dry material by conventional techniques is uneconomic, and fine dry particles on the surface of a disposal pile would create an excessive dust problem.

Moistened processed shale is, however, quite satisfactory for the disposal operation. Considerable work has been done by consulting soil mechanics laboratories to define its physical characteristics and this work has shown that processed shale, when properly moistened, can be readily compacted. When properly compacted, it has excellent weight loading characteristics, is substantially impermeable to the percolation of water, and is suitable for the construction of earth-fill dams.

An efficient procedure for moistening processed shale has been developed and tested at the Colony semi-works plant, and surface disposal operations with properly moistened material have confirmed its excellent characteristics. The material can be conveyed and spread without significant dust evolution and it can be compacted to form a hard, load-bearing surface with low dusting potential.

The improved disposal characteristics gained by moistening and compacting the processed shale are apparent from density data. Dry processed shale has a bulk density of about 70 pounds per cubic foot. With 10 weight percent water, and a practical level of compaction, the dry density (excluding the weight of water) can be increased to the range of 85 to 90 pounds per cubic foot. With an increase in water content to 20 percent, the optimum for achieving high compacted density, and with intensive compactive effort, a dry density of close to 100 pounds per cubic foot can be obtained.

(3) Underground Disposal of Processed Shale. One possible plan is to put the processed shale back in the mine. As already shown, except possibly in the lower zone, processed shale will not all fit back in the mine because its volume, even when compacted to commercially practical limits, is greater than that of the original raw shale and the space requirement for compaction equipment precludes full use of the underground confines. Further, in any plant and mine in a new area, it will be necessary to initially dispose of a substantial portion of the processed shale outside the mine since processed shale cannot, in a practical scheme, be returned to the mine until a large underground area has been established.

Although no field tests have been conducted on slurry disposal systems, it is estimated, based on laboratory tests and on experience with similar materials, that the dry density of slurry deposited fills will be in the range of 50 to 60 pounds per cubic foot. Assuming that 90 percent of the underground mine space can be used for residue storage, and that the dry density will be 60 pounds per cubic foot, only about 50 percent of the residue can be placed inside the mine.

Based on the assumption that a 50 percent solids slurry will be transported and that 50 percent of the water can be recovered from the settled slurry, water consumption for slurry disposal would be about 9 cubic feet per second for a 60,000 ton per day mining operation.

One possible disadvantage of using a slurry disposal method underground would be that contaminated waters from the slurry could pollute ground water.

About 6 cubic feet of water per second would be consumed for cooling and moistening processed shale for disposal, assuming a 20 percent water content. The dry density of compacted, moist residue is greater than the density of the slurry residue, and it has been variously estimated that up to 70 percent of the residue could be placed in the mine, versus 50 percent if the slurry method were used. Because of the lower water consumption and the lower space requirement, moistened residue disposal is presently considered the best disposal method to pursue. These advantages would likewise apply to surface disposal systems.

(4) Surface Disposal of Processed Shale. Laboratory and field work on disposal of processed shale produced by the TOSCO process has emphasized surface disposal. Surface disposal includes cooling and wetting, conveyor transport to the general disposal area, further transport to the specific disposal point, spreading, and compaction with conventional equipment. With these techniques, the placement procedure is similar to that used to form large earthen dams. Surface disposal also requires construction of necessary conduits, retaining dikes and terraces to prevent erosion, to contain surface run-off water and prevent downstream contamination, and to provide a satisfactory path for normal water flow.

The disposal pile can be contoured to blend in with the surroundings and revegetated to support natural flora. The vegetation and water diversion systems are designed to prevent wind and water erosion of the completed pile. A preliminary disposal plan for the model underground mine site has shown that the residue from a 20-year operation at 60,000 tons per day can be placed in two shallow canyons on the site with an areal coverage of about 1,520 acres. A sketch of this plan is shown in Figure 4.6. Disposal in a somewhat deeper canyon near the site has also been considered. This site would require about 1,100 acres for a 20-year operation (Figure 4.7).

Disposal and restoration costs for a surface disposal system such as those mentioned above have been estimated to be in the range of 10 to 15 cents per ton mined, or 2 to 3 million dollars per year, for a 60,000 ton per day operation. Although it is difficult to separate the incremental costs for environmental protection from the total disposal costs, these incremental costs have been estimated to be about 30 percent of the total disposal costs.

The above-mentioned plans are based on the assumption that all the residue from a 20-year

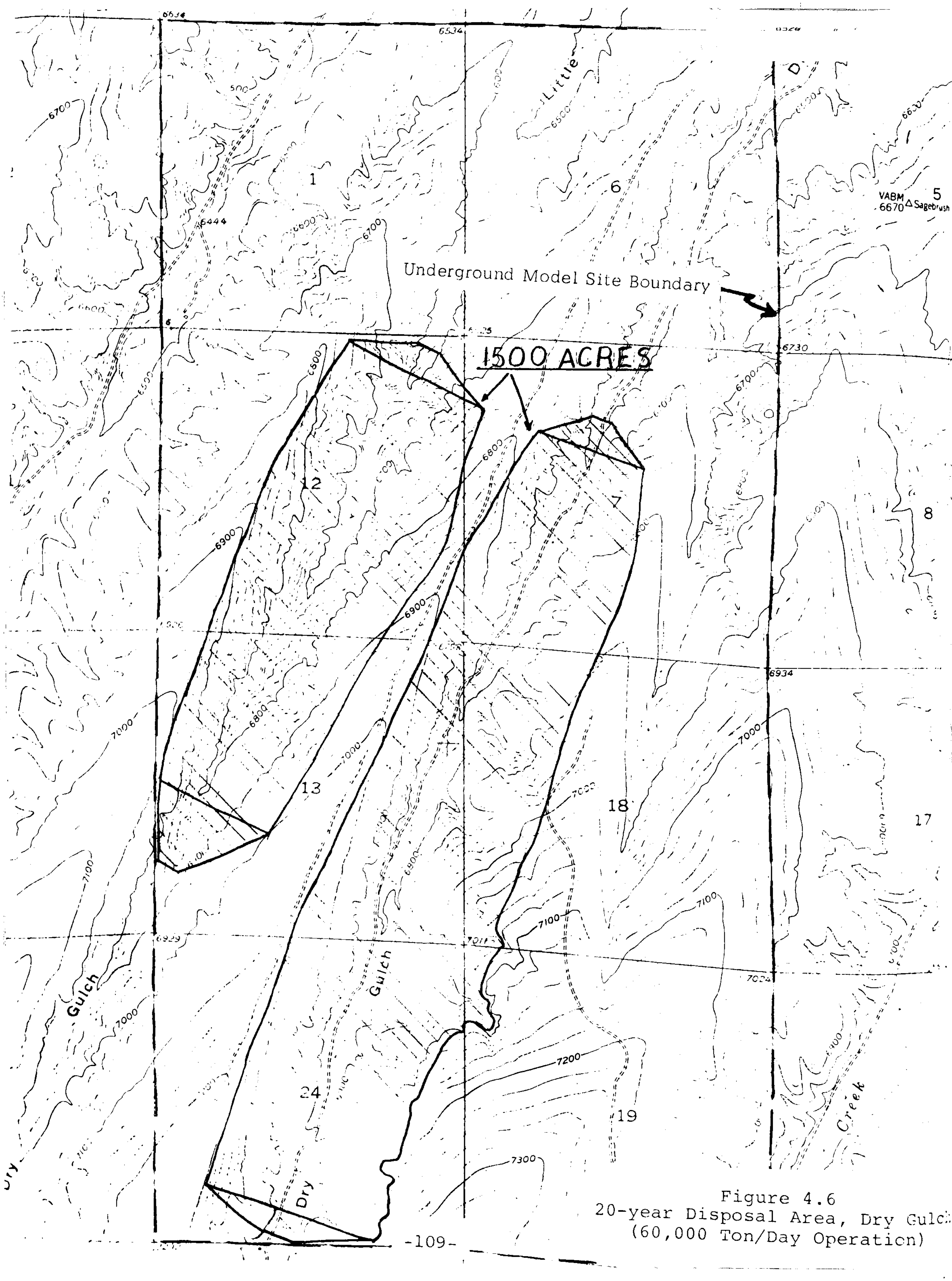


Figure 4.6
20-year Disposal Area, Dry Gulch
(60,000 Ton/Day Operation)

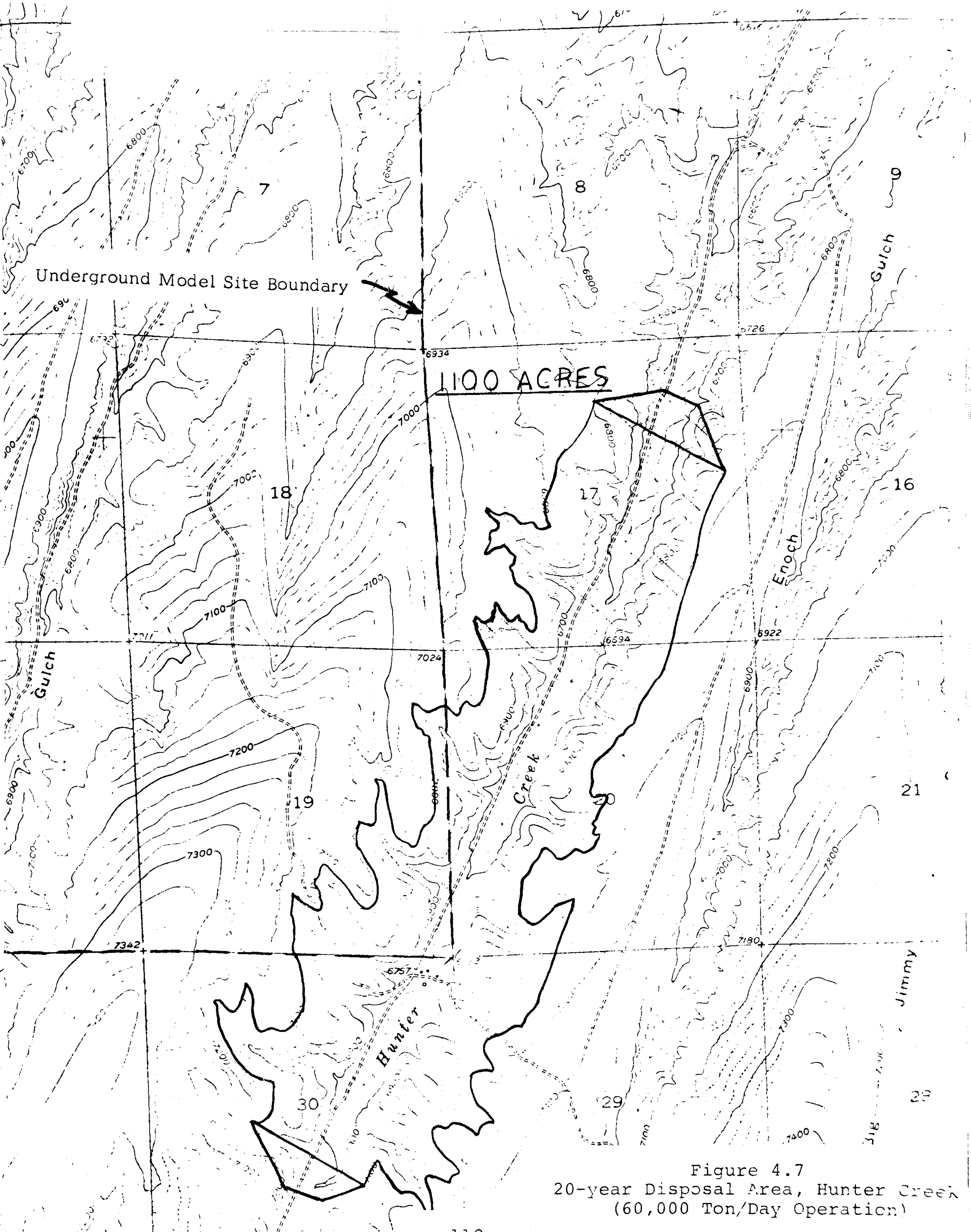


Figure 4.7
20-year Disposal Area, Hunter Creek
(60,000 Ton/Day Operation)

operation at 60,000 tons per day would be placed on the surface. However, if underground disposal proves technically feasible and environmentally advantageous, the surface disposal areas described above will suffice for operation beyond the 20-year time period. Assuming, as mentioned earlier, that 70 percent of the residue could be placed underground, the life of the disposal areas described above would effectively be extended from 20 years to about 70 years of equivalent operation. Without a detailed engineering study it is difficult to estimate the actual number of years of equivalent operation that the model test site reserves would provide. However, the principle of replacing part of the residue underground could apply in general to any underground mining operation.

The disposal plans discussed above were based on the assumption that environmental values would be best protected by locating surface storage sites in canyons to minimize the horizontal area needed for the disposal system. Other environmental considerations, such as the value of canyons as winter grazing areas for deer, must also be considered, however. Protection of the overall environmental values may require measures supplemental to basic plans discussed above. For instance, provision for substitute or invigorated winter browse may compensate, at least in part, for lands used in shale disposal.

(5) Processed Shale Vegetation. Observations of oil processed shale piles at Rulison and elsewhere indicate that natural revegetation occurs without artificial reseeding or fertilization. Considerable time, however, is required because the processed shale is alkaline and low in nutrients.

Extensive work has been done to develop practical methods for accelerating vegetation of processed shale. In the summer of 1967 a series of test plots was planted at the Colony semi-works plant.

Objectives of the program were to reduce the alkalinity, increase the nutrient level, and reduce the surface temperature, which tends to be high because of the dark color of the material. The plots were in four basic units for study of the effects of water rate, depth of planting, artificial seed bed cover, and soil treatments. It was found that by planting seeds 1/4-inch deep in leached soil, fertilizing, and covering with a commercial seed bed cover, a viable ground cover of native grasses was obtained.

Using the success of the 1967 tests as a guide, a demonstration plot was constructed on the processed shale site at the Colony semi-works plant in 1968. Working with the State Forest Service, deciduous and conifer trees were planted along the boundaries of the plot. Local shrubs and plants were also transplanted in the area in addition to native grasses. The results were good, although deciduous trees suffered badly from heavy snows, rolling rocks, and deer. The other plants were found to be hardy. The demonstration plot has now completed its third growing season with continued excellent results.

Dr. Laurence A. Schaal, a Consulting Agronomist, who is retired after 40 years with the U. S. Department of Agriculture, has been retained since 1968 to investigate the vegetation of processed shale. Colony is continuing, with Dr. Schaal's assistance, an experimental program in a Grand Junction, Colorado, greenhouse to develop improved techniques of processed shale treatment and to explore plant selection in an attempt to optimize vegetation procedures. Results show that the greatest deficiency with processed shale is its lack of nutrients, but that several local plants grow well in properly fertilized processed shale. The tests at the demonstration plot and in the greenhouse have shown that blue grass, crested wheat, Englemann spruce, salt bush and sagebrush grow well in properly treated processed shale.

In addition to revegetation of the disposal surfaces, consideration is being given to the further treatment of the permanent surfaces with broken rock and talus to provide erosion control and to blend the appearance of the surface with that of the surrounding terrain.

(6) <u>Water Quality</u>.

Regarding the effect of processed shale disposal on water quality, it is intended that the surface disposal system will include the following to prevent contamination of local streams by surface runoff from the disposal pile: (1) construction of a control reservoir upstream of the disposal pile, (2) installation of a conduit or other facility to transport water from the reservoir to a location downstream of the pile, (3) construction of a retaining dam downstream of the pile to collect surface runoff from the pile, and (4) pumping facilities to remove the collected water and deliver it to the process area for use in moistening processed shale.

The other potential source of water contamination in the processed shale disposal operation is percolation of water through the pile and into the underground or surface water system with a resulting increase in the dissolved solids content of the local watershed. As earlier explained, percolation is not expected to be significant because of the demonstrated low permeability of compacted processed shale. Since the anticipated disposal scheme restricts water on the surface of the pile to normal precipitation, the combination of low permeability, high evaporation rates experienced in Western Colorado, and normal plant use should avoid percolation of water through the pile.

(7) Further Program.

Although much has already been demonstrated on the technical and economic feasibility of surface disposal of processed shale from the TOSCO retorting process, considerable additional field work is planned as part of the forthcoming operating program at the Colony semi-works plant. This will include investigation of the level of moisture addition and degree of compaction, construction of test embankments, confirmation testing of the laboratory conclusions on permeability, and additional long-term field demonstration vegetation tests in cooperation with environmental and university consultants.

The program will also include tests and analyses to confirm the conclusion that the disposal pile will not result in significant increases in the dissolved solids content of underground or surface water. The work will include measurement of percolation tendencies in a test embankment. Related meteorological and hydrological studies are already in progress.

4.4 SHALE OIL UPGRADING.

(a) Introduction.

Shale oil is similar in most respects to conventional crude oil and can be processed by conventional techniques to form a range of high quality petroleum products including gasoline, jet and diesel fuels, and domestic and industrial heating oils.

The development of an oil shale industry will include refining of shale oil to finished products. However, it appears unlikely that a substantial refining industry will develop in the area of the oil shale deposits. The market for products in this area is small, and it is preferable, for economic reasons, to transport crude oil rather than a multiplicity of finished products.

It can thus be expected that the refining industry of the Rocky Mountain area will continue to be limited, as it presently is, to that necessary to supply the local markets. The substantial excess of crude now produced in the area is transported by pipeline to distant refining centers. Major refining centers are normally located in metropolitan areas to minimize the cost of delivering products to the market. Other important factors are access to water transport and availability of cooling water.

The preferred economics of transporting crude compared to finished products would, without other considerations, cause the refining of shale oil to be carried out in existing refining centers rather than in the Piceance Basin. An additional and perhaps even more compelling motivation for avoiding refining in the Piceance Basin is the limited availability of water. With modern refining techniques, but with significant economic penalty, water consumption can be restricted but not avoided. Thus refining in the Piceance Basin would, by competing for available water, limit the extent of crude shale oil production.

Although it is not expected that the development of a shale oil industry in the Piceance Basin will include substantial refining to finished products, it can be expected that early oil shale plants may include facilities for "upgrading" shale oil. Upgrading may be necessary because shale oil contains an unusually high concentration of nitrogen compounds, and these compounds deactivate catalysts used in many petroleum refining processes, including catalytic cracking, hydrocracking and reforming.

All conventional crude oils contain nitrogen compounds, with the amount varying greatly, depending on the source of the crude. Many California crude oils are classified as "high nitrogen" crudes, but even these have less than one-half the nitrogen content of shale oil. Most refineries, and particularly those that emphasize production of gasoline and other light products, have facilities to remove nitrogen. However, existing refineries could not cope with the high nitrogen content of shale oil if shale oil were a significant portion of the total refinery feed. Thus, the refining of shale oil to high value light products will require either that the nitrogen be removed from the crude shale oil or that the refinery processing the shale oil install additional nitrogen removal facilities.

The first generation oil shale producers may elect to install nitrogen removal facilities in order to increase flexibility in marketing the product. Once a shale oil industry is established, refineries in the existing refining centers will likely prefer to purchase crude shale oil and install in the refinery the additional nitrogen removal facilities necessary for processing shale oil.

The technology of nitrogen removal from petroleum oils has advanced considerably in the past ten years. The advance has been caused by the development of hydrocracking, a high yield process for conversion of heavy oil to gasoline and other light fuels. Hydrocracking catalysts are particularly sensitive to nitrogen compounds and thus considerable research and development has been directed toward techniques for removal of nitrogen. The predominant technique established for nitrogen removal is catalytic hydrogenation, in which the nitrogen is removed from the oil and converted to ammonia. The process also removes substantially all the sulfur from the oil and converts it to hydrogen sulfide. The ammonia and hydrogen sulfide thus produced can be readily recovered and separated. The ammonia can be directly marketed as fertilizer or a fertilizer raw material. Hydrogen sulfide is conventionally converted to sulfur.

Crude shale oil which has been subjected to the catalytic hydrogenation process described above is termed "hydrotreated synthetic crude." This material is a premium feedstock for refining into finished products. The hydrogenation not only reduces the nitrogen content to an acceptable level, but also reduces sulfur content to substantially zero and materially improves the API gravity.

(b) Process Description.

There are a number of possible processing sequences and proprietary processes suitable for removing nitrogen from shale oil. Figure 4.8 illustrates one set of alternatives that is applicable to the crude shale oil produced in the Union Oil or Anvil Points retorts. The crude shale oil is heated to vaporize a portion of it and the mixture of liquid and vapor is fed into a distillation column in which light oil, naphtha, and gas are removed from the upper parts of the column and heavy oil is removed from the bottom.

The heavy oil is further heated and processed in a delayed coking unit. The products from this unit are petroleum coke and a vapor stream containing gas, naphtha,

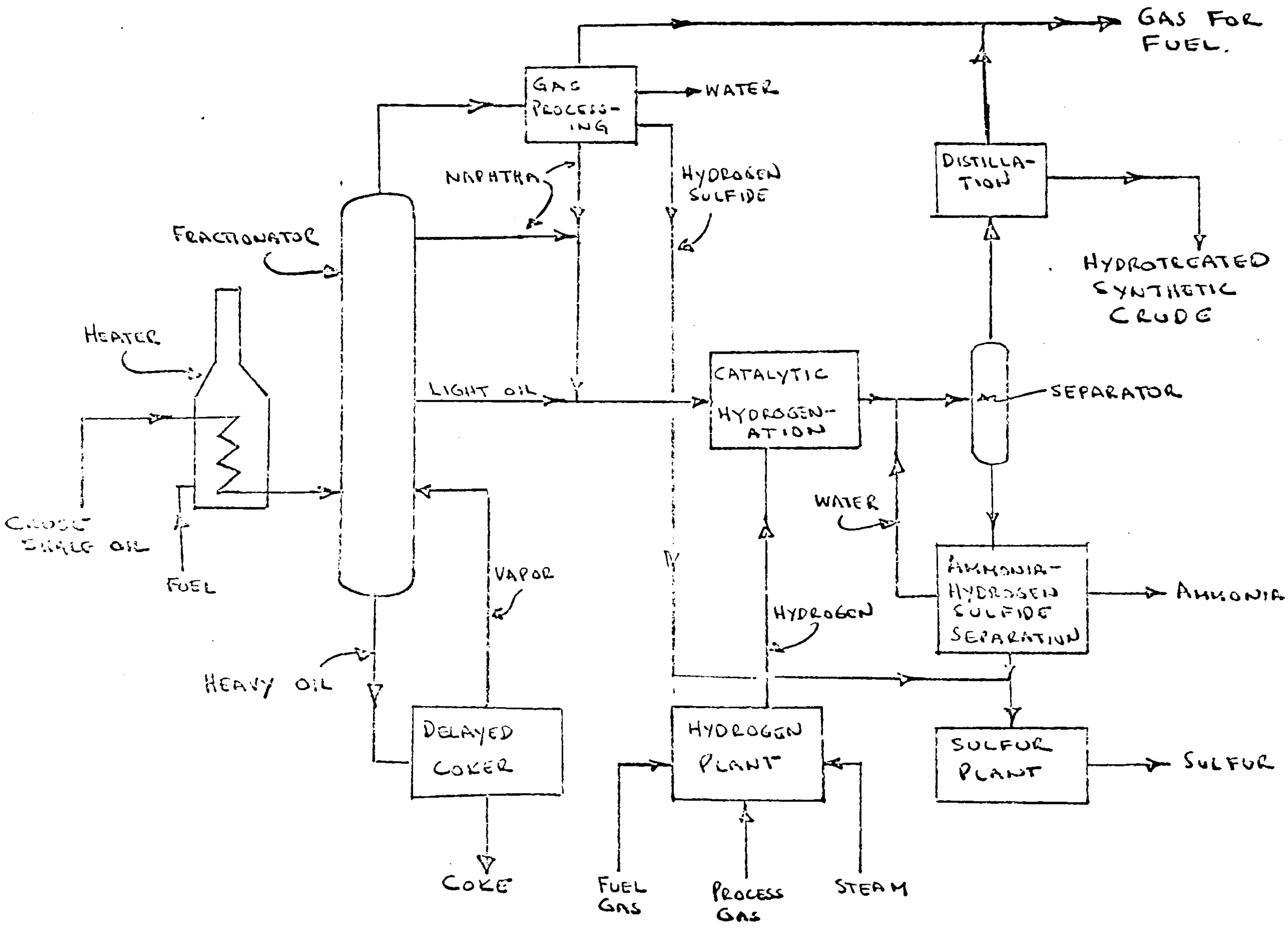


Figure 4.8
Shale Oil Upgrading Facilities

and light oil. This vapor stream flows to the crude distillation and gas processing units for separation of the various constituents.

Delayed coking is a thermal cracking process with chemical reactions similar to those in retorting, and the gaseous products formed are similar in composition to those formed in retorting. The gas processing shown in Figure 4.8 is similar to that expected to be utilized in the oil recovery section of the TOSCO process described elsewhere in this report. The products of the gas processing section are high quality fuel gas, light naphtha and by-product hydrogen sulfide which can be converted to sulfur.

The naphtha and light oil that are formed by retorting and by coking of the heavy oil are hydrogenated to remove nitrogen. The process includes heating the oil feed to an elevated temperature (600 to 850°F) and flowing it through a catalyst in the presence of hydrogen at elevated pressure (600 to 3000 pounds per square inch). The reaction produces sulfur-free, low nitrogen content synthetic crude, a small amount of gas and ammonia and hydrogen sulfide.

The total product from the hydrogenation unit is mixed with water to remove ammonia and hydrogen sulfide. This water stream is then separated by gravity from the oil and gas products and is then distilled to separate hydrogen sulfide and ammonia from each other and from the water. The water is recycled to contact the hydrogenation unit product. The ammonia is liquified for storage and sale as fertilizer or a raw material for fertilizer manufacture. The hydrogen sulfide is conventionally converted by the Clauss process to elemental sulfur and can be sold as such.

A small amount of gas is formed in the catalytic hydrogenation process. This is separated from the hydrotreated synthetic crude by distillation and can be used for plant fuel.

The hydrogen required in the catalytic reforming process is conventionally manufactured in the United States by reforming of natural gas or other light hydrocarbons by catalytic, high temperature reaction with steam.

There are a number of alternatives for the processing sequence show in Figure 4.8 including (1) addition of a second stage, vacuum distillation for the feed to cause more of the crude shale oil to flow directly to hydrogenation; (2) replacement of the delayed coking unit with a catalytic hydrotreating system designed for heavy oil; (3) separate hydrogenation units for the naphtha and gas oil; and (4) generation of hydrogen by partial oxidation of oil rather than reforming of light hydrocarbons.

The flow plan of Figure 4.8 should be somewhat modified for upgrading the oil formed by the TOSCO process. The main change is elimination of the crude distillation facilities. These are not needed because the fractionator in the oil recovery section for the TOSCO process produces oil in the desired fractions for further processing. In a plant which includes oil upgrading, this fractionator must be increased in size to accommodate the additional vapor flow from the delayed coking unit. The separate gas processing facilities shown in Figure 4.8 are also not required in an oil upgrading unit designed for the TOSCO process, since the oil recovery unit already contains such facilities.

All of the processing discussed above is conventional. Virtually all refineries include crude distillation and gas processing facilities. A large percentage of modern refineries, particularly those designed for a high yield of gasoline and distillate fuels, include coking, hydrogen manufacture and catalytic hydrogenation including related facilities for water washing and distillation of the reactor product. Many refineries also include plants for conversion of hydrogen sulfide to sulfur. The separation of ammonia from hydrogen sulfide is less common since few conventional oils contain sufficient nitrogen to make ammonia recovery economically attractive.

(c) Environmental Factors.

All of the processes shown in Figure 4.8 are in use in metropolitan areas of California under the regulations of the appropriate Los Angeles and San Francisco Bay Area air and water pollution control authorities.

(1) Air Quality Control. Large quantities of fuel are burned to supply process heat in the crude distillation unit, delayed coker, the catalytic hydrogenation unit, and particularly in the hydrogen plant. The total fuel consumption when processing 50,000 barrels per day of oil by the foregoing processing sequence can be expected to be in the order of magnitude of 1 billion BTU per hour. This heat load is equivalent to the consumption of approximately 25 million standard cubic feet per day of natural gas.

The major air quality control considerations with this upgrading process are emission of sulfur oxide and nitrogen oxide in the flue gas formed in the combustion operation. Sulfur oxides can be limited to the extent required by appropriate selection of the fuel. Nitrogen oxide emissions are controlled by design of the combustion unit to avoid excessive burning temperatures.

(2) Water Quality Control. The only significant production of contaminated water from the oil upgrading process is derived from steam condensed in

the gas processing facilities.

This water will have contacted naphtha and will contain dissolved organic compounds similar to those present in the water from the gas processing section of the TOSCO retorting process. Detailed development of the processing sequence must include investigation of techniques for purifying this water. As previously discussed with reference to the TOSCO process, the investigation should likely be directed toward treating the water to make it suitable for use in processed shale disposal. The investigation should include techniques now used successfully to purify sour water streams produced in conventional oil refineries.

Additionally, the upgrading facilities will produce some water from cooling towers which is high in dissolved solid content. This water can be used for disposal of processed shale or retort ash.

(3) Water Conservation. The upgrading facilities require not only a large input of process heat, but also substantial process cooling. With modern design techniques, this cooling can be almost totally achieved

by aerial cooling, thus largely avoiding consumptive use of water by evaporative cooling.

With extensive aerial cooling, consumptive use of water can be substantially limited to that necessary for process purposes. Uses in this category are modest and not expected to exceed two cubic feet per second for a 50,000 barrel per day operation employing the oil upgrading process described in this Section 4.4.

4.5 ASSOCIATED MINERAL RECOVERY.

Although most research and field operations have been directed toward demonstrating the commercial feasibility of extracting oil from oil shale, discoveries of sodium minerals at depth near the center of the basin in 1964 broadened the inquiry to include the mining and processing of nahcolite and dawsonite. Although no authoritative data have been published in this field, the following represents a brief summary of data now available:

(a) <u>Source</u>.

The recoverable concentrations of nahcolite and dawsonite are found in association with the oil shale in the Lower Zone, which is below the Leached Zone in the Parachute Creek Member (Section 2.3 and Figures 2.2 and 2.4).

(b) Process and Products.

The process would probably recover shale oil, alumina, and nahcolite. The nahcolite would be separated from the shale prior to retorting; the shale containing dawsonite would then be processed in the retort for recovery of shale oil; and the alumina would be recovered from the processed shale in a leach operation. The three-product operation would differ from a conventional one-product oil shale operation principally in the crushing and leaching steps.

(c) Mine Volume.

If nahcolite were removed from the shale prior to retorting, the mining operations would be larger than the retorting operations. Assuming 10 percent nahcolite removal prior to the retort, a 60,000 ton per day retort operation would demand a raw shale supply of 67,000 tons per day from the mine.

(d) Mine Method.

The underground mining method would probably be room-and-pillar, using the heading and bench technique.

(e) Water.

The "Lower Zone" is nonpermeable with very little fracturing except in major fault areas. Mining in the Lower Zone is expected to encounter little, if any, water. However, overlying the Lower Zone is the "Leached Zone" which contains large amounts of water and has a high porosity and permeability. Shafts into the Lower Zone can probably be sealed with concrete upon emplacement. A method of shaft emplacement which appears practical is drilling with large diameter rotary tools. A rotary drill shaft could be steel cased and cemented over the total shaft depth. Twelve to sixteen foot diameter tools are available at this time. The total shaft cementing should provide a sound seal through all possible aquifers.

(f) Processed Shale Disposal.

In a three-product operation, with the proper mineral mix, the volume of the mined area could accommodate all of the processed shale underground. Provided that underground disposal proves technically feasible and environmentally advantageous, the only surface storage of processed shale would be the amount which represents working room underground. The temporary processed shale storage should be located upstream from a retention reservoir designed to collect runoff water from the processed shale for reuse in the operation.

One estimate indicates that all of the processed shale can be returned underground, providing at least 20 percent by weight of the associated minerals is recovered. Returning the shale underground could be conducted in a manner which would provide structural support to the mine.

V. SURFACE MINING

5.1 INTRODUCTION.

This section describes a plan for an oil shale mining operation on the surface mining site. As with any large scale industrial activity, there are several potential sources of environmental degradation associated with such a plan. The major areas of environmental concern are disposal of solid wastes and disposal of excess water. These environmental factors and the related costs are discussed below.

5.2 BASIS.

First generation commercial retorting complexes will likely process oil shale yielding not less than 30 gallons of oil per ton. As retorting technology advances and operating experience is gained, it is possible that lower grade shale will become economically attractive. In this report, recoverable reserves are assumed to be shale yielding at least 25 gallons of oil per ton. For the 5120-acre model site selected, the recoverable reserves thus exceed 4.5 billion barrels. A reserve estimate based on 30 gpt shale for the same lease would be considerably less.

The Mineral Leasing Act of 1920 limits the size of a single lease to a maximum of 5,120 acres. Under the terms of a test leasing program similar to the one conducted by the U. S. Department of Interior in 1968, a lease may be further restricted in size to a maximum of 1.5 billion barrels of measured recoverable reserves, the development of which would create less severe environmental problems than discussed in this report. The larger reserve estimate used in this report was selected to illustrate probable methods of dealing with potential environmental damage in a typical surface mining situation. The resulting development plan and environmental protection measures described herein are based on established engineering practices, and for the most part are attainable with existing technology.

For the purposes of this study, a maximum oil production rate of 200,000 barrels per day was assumed.

It was further assumed that this level of production would not be achieved until the fifth year of operation. After retorting, about 80 percent of the raw shale weight remains as processed shale. Thus, for 200,000 bpd oil production from shale containing 25 gallons per ton, processed shale production would amount to 268,000 tons per day.

Shale oil and processed shale production schedules are summarized below. Based on the oil production schedule given, the mine would be in production for about 68 years.

SHALE OIL AND PROCESSED SHALE PRODUCTION RATES

Year	Shale Oil Production Barrels Per Day	Processed Shale Production Tons Per Day
1	10,000	13,400
2	25,000	33,600
3	50,000	67,200
4	100,000	134,400
5-68	200,000	268,800
Total over life of project	4.75 Billion Barrels	6.39 Billion Tons

5.3 DISPOSAL OF SOLID WASTES.

A development scheme for a mineral property the size and nature of that being considered here would require many months of detailed engineering analysis and could be justified only for an actual commercial project. The plan presented here includes what are believed to be adequate estimates of acceptable methods and costs for protection of the environment. The essentials of the scheme are shown in Figure 5.1 .

The area between the model site and the Cathedral Bluffs is not particularly attractive for surface mining because of the higher overburden to ore ratios encountered. It was therefore assumed that the area west of the model site would utilize some type of underground mining. Consequently, surface disposal of solid wastes in this area would be acceptable.

Contrarily, the area for several miles to the north, south, and east of the model site is amenable to surface mining. Solid waste disposal in these areas is unacceptable since it is expected that surface mining would be expanded in these directions.

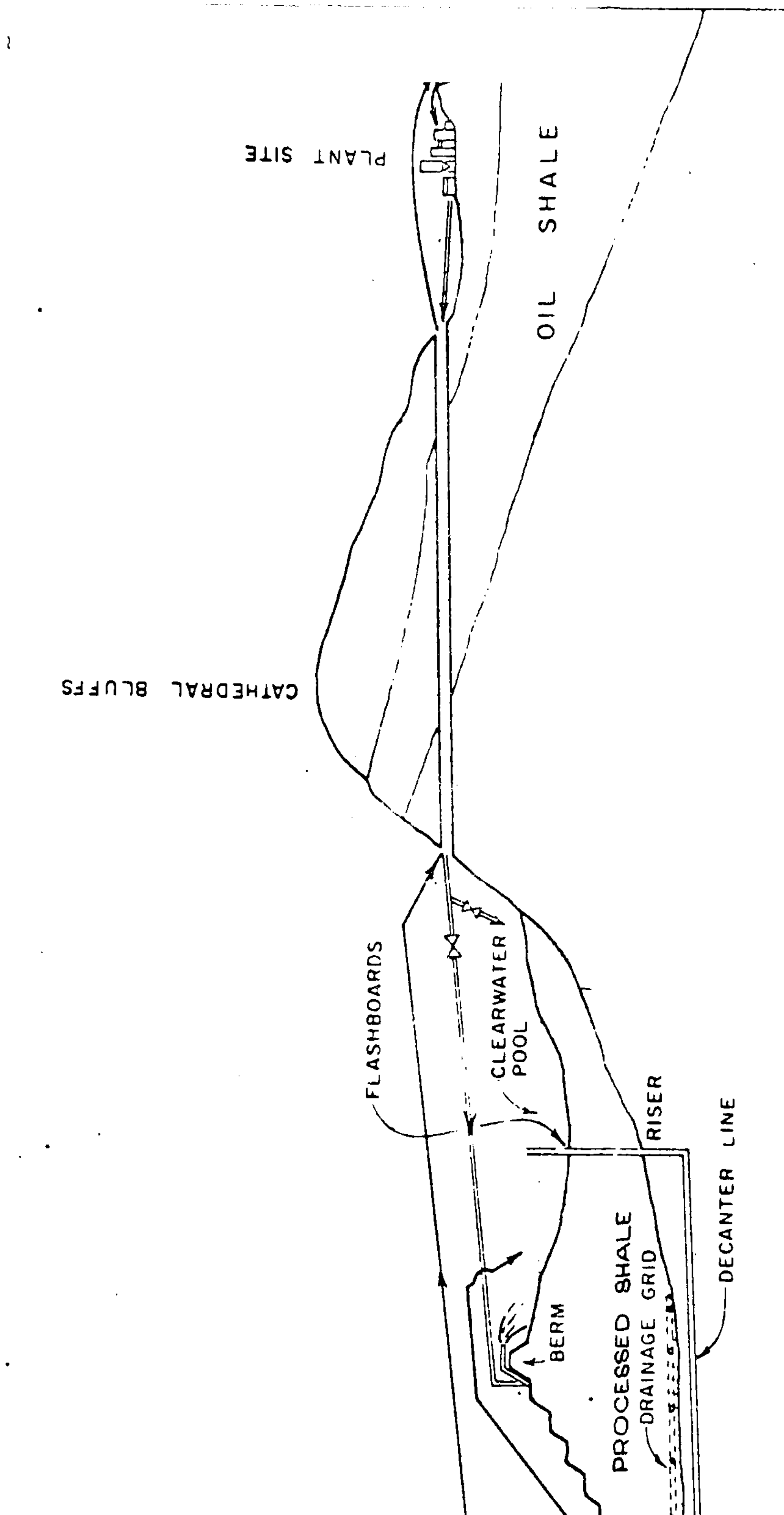


Figure 5.1- PROCESSED SHALE DISPOSAL SYSTEM CROSS SECTION SCHEMATIC

If surface mining eventually is expanded beyond the model site, it would be desirable to reserve some space during initial mining for solid waste disposal from later mine expansion. The waste disposal plan conceived here contemplates the use of part of the mined area for waste disposal from future mining operations.

(a) Overburden Disposal.

In the early years of pit development, overburden disposal will be off the site. As soon as development of the mine has reached a certain point, overburden will be returned to the pit.

The total amount of overburden to be disposed of during the life of the mine is estimated at 7.4 billion tons. This tonnage will occupy some 4.9 billion cubic yards. The required volume of offsite disposal is estimated to be 600 million cubic yards. A minimum of 8 years would be required before the backslope would be established and the pit area opened to a size permitting the placing of overburden into the pit. The pit floor at the end of 8 years would cover approximately 100 acres

Also, during the first 8 years, some 900 million cubic yards of oil shale would be mined, making the total pit volume 1.5 billion cubic yards at the time pit disposal of overburden would begin.

The area selected for offsite disposal is located at the northwest edge of the model site. The selection was predicated on the assumption that mining would begin in this portion of the lease tract.

The movement of overburden from the mine to the offsite disposal area would be accomplished by one of two methods, by truck or conveyor belt. Belt haulage would be the cheaper of the two, but initially truck haulage will be necessary until slopes are developed for installation of conveyor belts.

The 600 million cubic yard offsite disposal requirement would ultimately affect some 1,000 acres of land. The dump would resemble a mesa having an elevation of approximately 8,100 feet. The top would be moderately sloped to permit surface drainage. The sides would be constructed in benches of appropriate height and width to permit reclamation and revegetation when the area is no longer needed. Revegetation would be started in the early years and completed shortly after pit disposal of overburden begins.

(b) Processed Shale Disposal.

The total volume of processed shale requiring disposal throughout the life of the model site is estimated at 5.9 billion cubic yards. Pit disposal of processed shale is not contemplated during the life of the model mine. As indicated earlier, it would be desirable to reserve some of the volume created by first generation mining for solid waste disposal from later mines in the area. This pattern of development, one mining operation filling the void created by an earlier operation, would result in the disturbance of the least amount of surface. To do this, however, permanent offsite disposal of all the processed shale from the first generation mine is required.

The dry canyons immediately west of the Cathedral Bluffs are well situated for disposal of processed shale from a retorting plant on the western edge of the model mine site. There are several reasons supporting this selection, namely:

- only land which is devoid of oil shale, or other known deposits of valuable minerals, would be permanently covered.
- a smaller surface area would be affected than if the same volume of processed shale were deposited anywhere east of the bluffs.
- processed shale would be kept out of the mine where it might interfere with operations.
- the disposal system probably is the most economic method of processed shale disposal.

Transporting very large tonnages of processed shale from the model site to areas west of the Cathedral Bluffs is a formidable engineering problem, but the surface topography of the area provides a possible solution.

The lease site, with an average elevation of 7,200 feet is some 1,200 feet higher than Douglas Creek, which would roughly mark the western limit of the processed shale disposal area. The eastern boundary of the disposal area is at an elevation of approximately 7,000 feet. From a retorting plant site just west of the mine at an elevation of 7,600 feet, a 3.5 mile tunnel sloping to the west would connect the plant and the disposal area. The processed shale would be mixed with water and the resulting slurry permitted to flow by gravity through a pipeline installed in the tunnel. Beyond the tunnel portal on the west, the pipeline would extend to the lower end of the canyon where disposal operations were being conducted. Several canyons would be required for processed shale disposal over the life of the mine. The procedure would be to fill one, then move on to the next. Thus, revegetation in each canyon could be started as soon as disposal in that canyon is completed.

Essentially, a large dam of processed shale extending several hundred feet upstream would be built in each canyon. A small dam or berm, perhaps no greater than 30 feet in height, would first be constructed of native materials across the canyon near Douglas Creek. Below this dam a second small impoundment dam would be constructed to contain seepage and runoff. The slurry of processed shale and water would be discharged through a series of nozzles behind the small dam. When the processed shale behind the dam has risen to its crest, another berm would be built inside the upper edge of the first dam. Processed shale would be used in constructing the second berm. The slurry delivery system would then be relocated to discharge behind the second berm and the process repeated until the full height of the processed shale dam is reached. At that point, the processed shale slurry could be discharged anywhere upstream and permitted to flow in behind the dam.

As the slurry is deposited behind the dam, the solids would tend to settle out of the mixture, leaving a pool of water essentially devoid of suspended solids. The water would, however, be high in dissolved solids and highly saline, and thus could not be discharged into Douglas Creek. This water would instead be recycled to the plant site east of the Cathedral Bluffs and reused to form slurry. As the dam of processed shale grows, a combination of natural desiccation and an interior drainage system would reduce the moisture content of the deposited processed shale to 20 percent by weight or less. At this moisture level, compaction to a dry density of approximately 90 pounds per cubic foot could be attained. As compaction increases, permeability of the processed shale dam will be significantly reduced. Because of the low permeability and the superior strength characteristics, the resulting processed shale dam should be adequate to prevent downstream pollution and to contain the disposal area behind it.

During the early stages of the dam building process, there would be vulnerability to flash floods common to the area. Protection against flood water would be provided by canals located upstream. These canals would intercept storm runoff and carry the water around the dam into Douglas Creek. Flood waters would not be allowed to come into contact with processed shale.

The processed shale disposal system described above and shown schematically in Figure 5.1 would eventually fill seven canyons and cover an area of approximately 12,500 acres. The net effect of the disposition of processed shale west of the bluffs would be to convert eroded canyon land to a gently sloping fluvial plain with only the crests of ridges rising above the processed shale.

5.4 DISPOSAL OF EXCESS WATER.

Presently available geohydrologic data indicates a large volume of groundwater in the Piceance Creek Basin. Although much of it is probably not potable, oil shale retorting, shale oil refining, and solid waste disposal could benefit if such supplies were available for use without detrimental consequences. In fact, it is probable that a surface mine site would encounter an excess of groundwater that would require disposal.

Estimates vary as to exactly how much groundwater might be encountered from a surface mine at the model site. One estimate based on limited hydrologic testing is on the order of 30 cubic feet per second per square mile of mine area. A mining operation of the size described in this chapter would expose a square mile of water bearing formations in a very few years. The reported figure of 30 cfs is equivalent to 13,465 gallons per minute. Other estimates range upward from this figure.

Again based on limited tests, some of the water is indicated to be of high quality, but much is saline. Potable water should be segregated from saline water during mining operations. The disposal or use of potable water obviously is no problem.

Water requirements for the processed shale disposal system described above have been estimated to be 30 cubic feet per second. Much of the saline water, therefore, would be used for this purpose. There are other low-grade uses for saline water in the oil shale processing complex which would accompany the mining operations. If there were excess saline water requiring disposal, none of it should be discharged into surface streams in the area.

Pumping the saline water back into the aquifers from which it originates is a possible disposal method, provided adequate safeguards against degradation of underground water systems are available.

There is a possibility that excess water, even though of poor quality, would be valuable to ancillary industrial activity in the area and even to other oil shale processing plants.

5.5 COST ESTIMATE.

The cost over the life of the project for overburden and processed shale disposal would amount to approximately 31 cents per barrel and 11 cents per barrel, respectively. An initial capital investment on the order of $120 million would be required to effectively undertake the disposal plans as described in this report. It is expected that this would amount to 10 to 15 percent of the total capital investment for the development of the property. The costs are further summarized below.

ESTIMATED COST OF OVERBURDEN AND PROCESSED SHALE DISPOSAL

Item	Initial Invest.	Deferred Invest.	Life Oper.Cost	Total	Cost Per Barrel
	.... Million Dollars			....	.dollars.
Processed Shale Disposal	30	34	470	534	0.11
Overburden Disposal	86	247	1110	1442	0.31
Total	116	281	1580	1976	0.42

As has been previously mentioned, it is difficult to separate the costs for environmental protection from normal disposal costs. If, as in previous sections, environmental costs are assumed to be 30 percent of the total disposal costs, such costs would amount to approximately 13 cents per barrel of oil produced.

VI. IN SITU OPERATIONS

6.1 STATE OF IN SITU TECHNIQUES.

"In situ" oil shale operations contemplate removal of the oil from the shale by heating the shale while it is underground. Various means of applying heat have been proposed and several have been tested in field experiments, but a commercial technique has yet to be demonstrated. Presently proposed heat sources include underground combustion, hot natural gas, hot carbon dioxide, superheated steam, hot solvents, and combinations of two or more of these. It is anticipated that paths for introducing heat underground could be provided through wells, mine shafts and tunnels, fractures created by a variety of techniques (including nuclear explosion), or by a combination of these.

In 1953-54, Sinclair tested in situ combustion near the edge of the oil shale cliffs six miles northwest of Grand Valley, Colorado. It was concluded from the tests that: (1) communication could be established between wells through induced or natural fractures, (2) oil shale could be ignited underground, and (3) combustion could be maintained and shale oil recovered (Appendix 6.1). In 1964 Sinclair undertook field work in the deeply buried oil shales along Yellow Creek in Rio Blanco County, Colorado. No results were published.

Equity Oil Company has operated an in situ experiment along Black Sulphur Creek in Rio Blanco County since 1964. The Equity process employs injection of hot natural gas through a well drilled into a zone of oil shale with native porosity and permeability where it gives up its heat, thereby retorting the shale. The gas and oil evolved are produced through wells which communicate with the injection well through the permeable zone. Equity has reported that ". . . in situ retorting of oil shale using heated natural gas is a feasible and potentially economic method for the recovery of oil from oil shale." (Appendix 6.2)

Over the past five years, the Bureau of Mines has performed numerous shallow in situ experiments near Rock Springs, Wyoming (Appendices 6.3 and 6.4). It has successfully induced fractures between wells using high voltage electricity and hydraulic fracturing; in addition, it has created fractured zones by use of liquid explosives. Some oil has been recovered from the fractured shale using hot gas without combustion and also by means of in situ combustion. The Bureau's attempts to produce oil by injecting superheated steam were not successful.

Mobil, Humble and Shell have carried out field work connected with in situ recovery at various times within the past ten years, but have not published reports. Shell is currently undertaking an in situ research project on Piceance Creek in Rio Blanco County, Colorado.

6.2 ENVIRONMENTAL PROBLEMS AND PROTECTION.

It is obvious that in situ techniques present environmental problems and questions different from those presented by underground mining and surface retorting techniques. The primary differences are that the surface operations are substantially smaller in scope than in situ recovery, and the problems associated with mining and processed shale disposal are not present.

In situ surface and drilling operations are more closely analogous to conventional petroleum industry techniques for thermal recovery of heavy crude oil.

In a thermal project, the oil-bearing formation is heated by hot fluids or gases or by underground combustion so as to reduce the viscosity of the oil and enable it to be produced through a well to the surface. In situ shale oil processes can be expected to use many of the same types of equipment and operations as thermal projects. Techniques for environmental protection in thermal projects have been fully developed by the petroleum industry and should be adaptable for use in in situ projects. To the extent that thermal recovery and in situ are substantially parallel - particularly surface and drilling operations - the problems and solutions are conventional. Potential environmental problems associated with air protection and land protection are minimal, while those associated with water protection are more significant.

(a) Air Protection.

For in situ oil shale operations, potential air pollution would come from conventional sources such as internal combustion engine exhausts, burner combustion products, and gas and vapors associated with shale oil production. These pollution sources could be controlled by conventional methods of controlling combustion and removing pollutants from gaseous and liquid effluents.

(b) Land Protection.

Because most of an in situ operation takes place below ground, disturbance of the original land surface and vegetation is expected to be minimal. It is anticipated that less than ten percent of the land surface over an in situ recovery project will be affected at any one time. Earth moving will be limited mostly to grading for well locations, a plant site, and field roads. Erosion will be controlled by proper grading, mulching, and revegetation.

Upon completion of production from part of an area, wells or shafts will be plugged, roads and well sites plowed, and the surface revegetated with native cover. When an entire in situ recovery project is finished, equipment will be removed from the plant site, pits will be filled, foundations broken up, and the site revegetated. Thus, any environmental elements, including wildlife habitats, disturbed by the operation, will be essentially restored.

(c) Water Protection.

Substantial amounts of water likely will be produced along with the shale oil during any in situ operation. It is anticipated that this water will be hot and contain dissolved saline compounds.

Depending upon the volume produced and the nature of the operation, this water can be handled in one or more ways so as not to pollute surface and underground waters of the area. Possible measures to prevent pollution during water disposal include injecting the excess water into a hydrologically isolated subsurface formation containing nonpotable water, or treating the water so it can be released into local groundwater systems.

Methods of preventing pollution by contaminated water or oil during normal operations include designing the wells with sufficient casing to protect both surface and underground waters; designing pits, tanks and other vessels to be leakfree and isolated by terrain or dikes so there will be no danger of overflow into a stream; and designing system safeguards so that in the event of mechanical failure the producing system can be safely shut in.

To the extent that these water protection problems and solutions, which have been applied with success in thermal recovery, are applicable to in situ operations, no novel difficulties are foreseen. However, the analogy to thermal recovery may not be fully applicable to oil shale in situ operations in the Piceance Creek Basin, and accordingly, more information will be required to assure the absence of surprises. The geology of the oil shale formations is substantially different from the relatively permeable oil-bearing formations to which thermal recovery has been applied. It is known that large quantities of underground water exist in the Piceance Creek Basin, but the precise locations, composition and movements of these waters is not precisely known. Until more is learned, disturbance of the waters necessarily involves some risk.

The problem of applying thermal technology to in situ operations is complicated by the existence of impermeable zones. All presently contemplated techniques for in situ operations involve establishing permeability, either by electric and hydraulic fracturing, or by the use of explosives, either conventional or nuclear. The creation of new fractures can change existing hydrology, thus introducing new unknowns.

The use of nuclear explosives to induce fracturing obviously presents potential problems concerning atmospheric venting of radioactive substances, radioactive contamination of underground waters, residual radioactivity in produced hydrocarbons or water, and undesirable seismic effects.

6.3 ECONOMICS.

It is not possible to estimate the cost of environmental protection for in situ shale oil recovery until a commercial process is fully designed. However, from analogy with oil field thermal recovery processes, it is anticipated that, in the absence of special problems, the cost of meeting regulations for environmental protection will not be so great as to destroy the economics of an otherwise viable process.

VII. OFF-SITE REQUIREMENTS

Off-site requirements of an oil shale plant and mine combination would include roads, electric and gas power transmission facilities, water transmission facilities, oil pipelines, and provision for a full range of community services.

7.1 ROADS.

Present access to the area of the model lease sites is by Highway 13 from Rifle to Rio Blanco and by the county road from Rio Blanco along Piceance Creek to and from the junction with Colorado 64. Roads from the plant sites to the Piceance Creek road would probably follow the natural drainage patterns. Rio Blanco County has recently improved the county road from Rio Blanco along Piceance Creek to the junction of Colorado 64, and has installed a number of underpasses designed to permit the movement of deer and cattle from one side to the other.

The commencement of commercial activity in the vicinity might require additional improvement of the Piceance Creek Road and will necessitate the improvement of Highway 13 between Meeker and Rifle to handle the increased volume of traffic resulting from the industrial activity. Special study should be devoted to the effectiveness of underpasses and drift fences now in operation in the Piceance Creek area and elsewhere to evolve satisfactory methods of reducing highway deer kill and minimizing interference with deer migration patterns.

Some State and Federal game management personnel have suggested the importance from the recreational access standpoint of opening the south portions of the Piceance Creek Basin by a road up Roan Creek or Parachute Creek and out over the escarpment at the head of one of their tributaries. This would tend to increase the likelihood of dispersion of the residential accommodations of plant personnel mentioned in Section 7.3, "Personnel."

7.2 POWER.

Power requirements for an oil shale mine and processing plant would be of two kinds: natural gas and electricity. Natural gas is desirable in the hydrogenation process, but may be supplanted by process-generated gas. Electricity is necessary for a variety of mine and plant uses.

(a) Natural Gas. The basic problem with natural gas as a source of power is the short supply in the vicinity of the Piceance Creek Basin. There are, however, areas of potential supply nearby awaiting markets for possible development. Oil shale plants in the Piceance Creek Basin would presumably be serviced from either of two existing pipeline systems in the area. One of these systems is presently serving the Equity Oil Company in situ oil shale site and the Shell Oil Company oil shale site westward from Piceance Creek. The extent to which gas is used will be a primary function of the volume required and the price at which this fuel can be delivered to the area.

The patterns of connecting pipelines would not necessarily follow drainage patterns, but would follow direct lines from the plant to the nearest point on the line. Known techniques for filling the pipeline excavation and reseeding the right-of-way, supplemented by advice from agencies working on plant revegetation programs, should provide adequate techniques for restoring the disturbed surface. The two most recent activities of this type in the State of Colorado were the natural gas pipelines constructed over Corona Pass in 1969 and over Straight Creek in 1970, both constructed by one of the pipeline systems presently operating in Piceance Creek Basin.

(b) Electricity. High voltage power lines presently exist to the north, to the east and to the south of Piceance Creek Basin. Although these power lines are in the proximity of the basin, electric requirements for a sizeable oil shale development at the model sites would necessitate construction of additional high voltage power lines.

Much of the area over which these new power lines would be constructed is public land. While the power supplier constructing such facilities should recognize today's environmental matters as a normal procedure, particular attention can be given to the construction practices and criteria outlined in the recent Department of Interior and Department of Agriculture document entitled "Environmental Criteria For Electric Transmission Systems" (U.S. Government Printing Office:

1970 0-404-932). Adoption by the electric power supplier or suppliers of such criteria will assure adequate environmental planning for these off-site facilities.

It is quite likely that regulatory authority would be required for construction of new high voltage electric facilities to the area of the model sites.

7.3 PERSONNEL.

The number of employees required to man the mine and plant capable of extracting and processing 60,000 tons of oil shale per day will be 900 to 1,000. Applying the data developed by J. J. Ryan and J. G. Welles in their work, Regional Economic Impact of a U. S. Oil Shale Industry, 1966, Denver Research Institute, to determine the resulting population which could be expected from this employment, one should anticipate the need to accommodate a population growth of not less than 4,500 persons. It is agreed by most students of the problem that the existing communities of Meeker, Rangely, Rifle, Glenwood Springs, and Grand Junction are best equipped to absorb this increase in growth and that efforts should be directed along the lines of supplementing the housing, educational, and other facilities of these communities to absorb this population growth.

Except for custodial personnel, it is not expected that plant personnel will live in the vicinity of the plants. As indicated in the section entitled "Land Use Planning," particular efforts should be made to avoid the creation of unplanned roadside communities outside of the existing communities.

A special study should be made of the possibility of providing payments in lieu of ad valorem taxes to Garfield County and other counties if, as can be anticipated, a substantial number of plant personnel elect to live elsewhere than in Rio Blanco County. Employment patterns in Western Colorado indicate highly dispersed living patterns, suggesting that a significant proportion of personnel would live as far west as Grand Junction and as far east as Glenwood Springs. If this is the case, special arrangements may be necessary or desirable to avoid disproportionate community burdens resulting from these population demands.

7.4 SHALE OIL PIPELINES.

Shale oil from processing plants in the Piceance Creek Basin would be moved to refining centers via pipelines. Part of the product oil may move west to Salt Lake City or Los Angeles; however, it is likely that most of the oil will move east to Chicago and other mid-western refining centers.

There are several possible routes for a pipeline to connect with existing pipelines to mid-western areas: (1) north to Wamsutter, Wyoming, and then to Casper to connect to the Platte or Service lines moving east, (2) directly east to Laramie to connect with either of these lines, and (3) south to Rifle and thence along the railroad or a highway right-of-way to the Denver area for connection with the Arapahoe line near Sterling. A portion of the oil could go west to Utah. The principal existing lines are shown on Figure 7.1, with possible oil shale connecting lines shown as crossed lines.

Environmental considerations in the construction of these shale oil connective lines are not unique to the

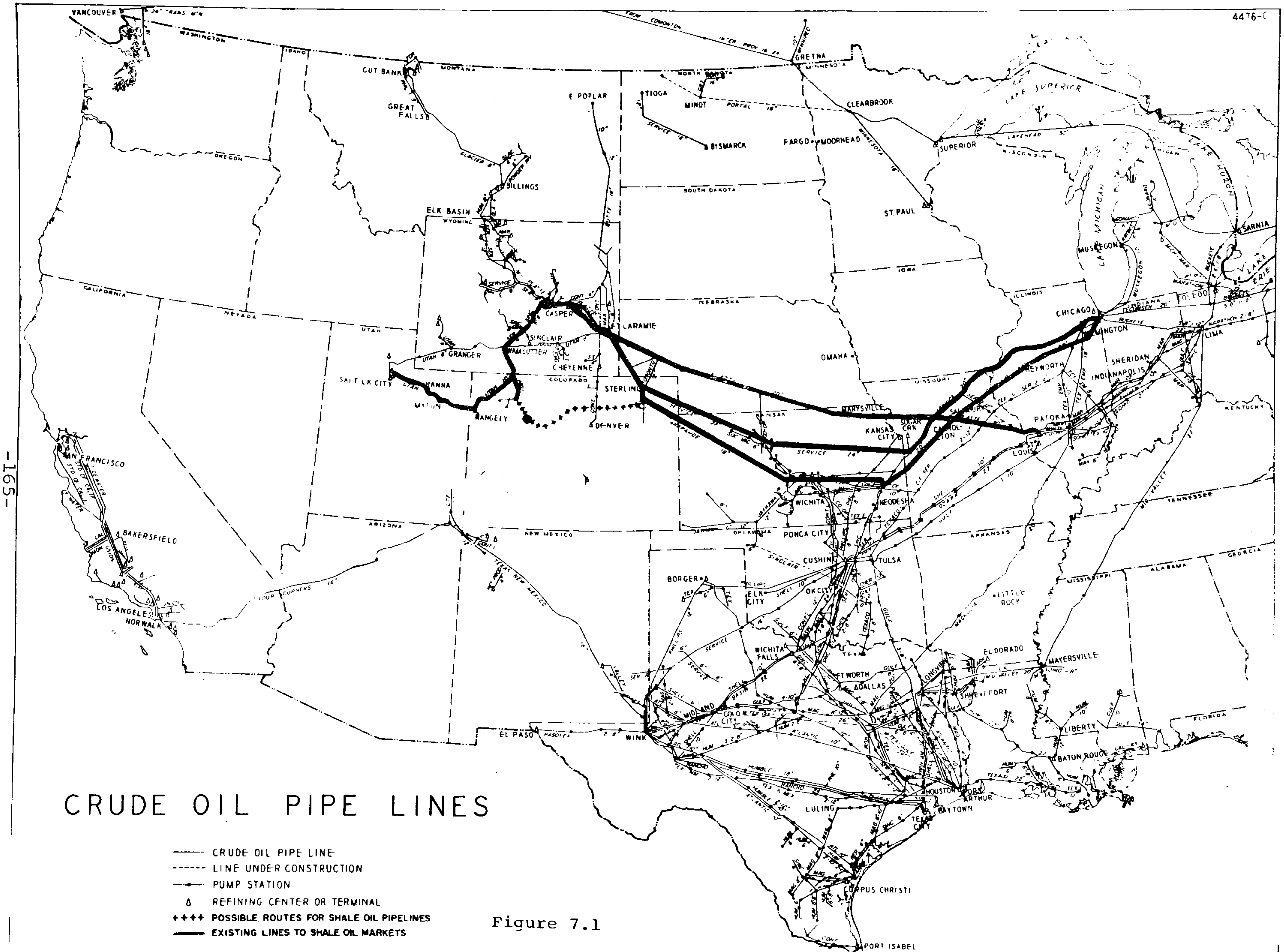

4476-C
CRUDE OIL PIPE LINES
CRUDE OIL PIPE LINE
LINE UNDER CONSTRUCTION
PUMP STATION
REFINING CENTER OR TERMINAL
++++ POSSIBLE ROUTES FOR SHALE OIL PIPELINES
EXISTING LINES TO SHALE OIL MARKETS
VANCOUVER
CUT BANK
GREAT FALLS
BILLINGS
ELK BASIN
E POPLAR
TIOGA
MINOT
BISMARCK
GRETNA
CLEARBROOK
FARGO
MOORHEAD
SUPERIOR
ST. PAUL
CASPER
LARAMIE
SINCLAIR
WAMSUTTER
GRANGER
CHEYENNE
SALT LK CITY
HANNA
MYTON
RANGELY
STERLING
DENVER
OMAHA
MARYSVILLE
KANSAS CITY
SUGAR CRK
CHICAGO
MUSKEGON
SARNIA
TOLEDO
LIMA
SHERIDAN
INDIANAPOLIS
PATOKA
ST. LOUIS
WICHITA
NEODESHA
PONCA CITY
CUSHING
TULSA
BORGER
ELK CITY
OK CITY
LITTLE ROCK
WICHITA FALLS
FT. WORTH
DALLAS
MIDLAND
EL DORADO
MAYERSVILLE
SHREVEPORT
LIBERTY
BATON ROUGE
EL PASO
WINK
HOUSTON
BAYTOWN
LULING
CORPUS CHRISTI
PORT ISABEL
SAN FRANCISCO
BAKERSFIELD
LOS ANGELES
NORWALK

Figure 7.1

oil shale industry. Care must be exercised in the construction and maintenance of lines to insure minimum disturbance of the surface, including appropriate revegetation. Wherever possible, the line or lines should follow existing rights-of-way.

VIII. LAND USE PLANNING

8.1 INTRODUCTION.

The population of Western Colorado is relatively small and the largest community, Grand Junction, has a population in the urban area of approximately 30,000 persons. The major east-west highway of Colorado is Interstate 70, now under construction along the Colorado River, generally the southern boundary of the principal oil shale area, as is the route of the Denver and Rio Grande Western Railroad main line. The northern boundary of the shale area is approximately marked by the White River Valley, a remote and isolated valley in a thinly settled area with two communities, Meeker and Rangely, each having a population of about 1,500.

The principal industries in the region are grazing of livestock and the extraction of minerals. Rangely, in Rio Blanco County, is the site of Colorado's largest oil field, and exists principally as an oil and gas center. Grand Junction, the principal community of Western Colorado, is a transportation hub with rail, truck and highway communication with Western Colorado and more distant points, and with frequent jet air service principally to Denver and Salt Lake City. Grand Junction is also a commercial and medical center for the region with a number of wholesale supply firms and services, as well as medical, educational, and other professional services.

Rifle, situated in Garfield County on the Colorado River at the southwestern corner of the Piceance Creek Basin, has historically been oriented more towards industrial activity. It is the site of the Union Carbide vanadium-uranium mill and is the nearest community to the Bureau of Mines' plant at Anvil Points. The Denver and Rio Grande Railroad has made it a shipping point for livestock from the Piceance Creek Basin. A significant portion of the manpower needed for an oil shale industry in Rio Blanco County can be expected to locate in Rifle.

To the east is the county seat of Garfield County, Glenwood Springs, situated at the junction of the Roaring Fork and Colorado Rivers. This community has become the focal point of distribution of goods and services to the very large areas drained by the Colorado, Eagle, Roaring Fork, Frying Pan and Crystal Rivers. In addition, it has been a center for local State and Federal offices. It has a population of about 4,000 and is well served by medical and educational facilities. It is expected to absorb some of the population growth flowing from a leasing program.

The communities of New Castle, Silt, Grand Valley and Debeque on the Colorado River will take on added significance as population centers, but are not expected to absorb a major share of any population growth derived from leasing oil shale reserves in the Piceance Creek drainage area, at least in the early phases of its development.

In 1964 Rio Blanco County, which now has a population of about 4,800, became concerned generally with the increasing pace of recreational land sales and with the possibility of the rapid development of an oil shale industry. The Board of County Commissioners appointed a planning commission which, in turn, engaged Small, Cooley and Associates of Denver as planning consultants, and commenced public hearings and meetings towards the adoption of a master plan, planning, and zoning for Rio Blanco County. Because of the sparse population, the predominantly agricultural use of the land in the county, the uncertain course of oil shale or recreational development, and some unsatisfactory experiences with land planning and zoning elsewhere in Colorado, the following course was adopted:

(a) The planning commission members were selected from strong community leaders over the entire planning area.

(b) Consistent with the Colorado statutes, both the voting members and the associate members of the planning commission participated fully in the plans and consideration of the commission's activities.

(c) A number of public meetings were held, with fullest possible publicity and many opportunities for public discussion and information about the proposed plans.

(d) No precise or specific planning for large development was made in anticipation of the need.

(e) The plan was intended as a beginning only, and was subject to periodic update and change.

Because a previous planning board in the community and area of Rangely had adopted a plan for the development of Rangely, in the west end of Rio Blanco County, the Rio Blanco County Planning Commission was given jurisdiction over the easterly two-thirds of Rio Blanco County. The approximate western limit of the jurisdiction of the commission is the Cathedral Bluffs, the westerly edge of the Piceance Creek Basin, and for this reason substantially all of the oil shale reserves in the northerly Piceance Creek Basin are within the jurisdiction of the Rio Blanco County Planning Commission.

In 1964, when there were many predictions of the immediate development of an oil shale industry employing thousands of people with an influx of industrial developers and land speculators, the planning commission developed subdivision regulations and a mobile home regulation. These regulations were adopted by the Board of County Commissioners early in 1965.

In the Subdivision Regulations of Rio Blanco County, covering by far the greater portion of the Piceance Creek Basin, are protections against the speculative development of unimproved land, and sales of land by mail, as well as protection against strip development of land along, for example, Piceance Creek or one of its tributaries. The general requirements in design standards of the subdivision regulations are stringent, and require minimum lot size of at least five acres for lots not served by a public water and sewer system. This requirement, although unpopular generally for the first few years in which it was in effect, is gaining in popularity in the community, particularly as the results of the five acre limitation are more apparent. This limitation tends to discourage cheek-by-jowl development of small cabin sites and trailer camping places, with attendant problems of water pollution. The requirement has tended to encourage construction of retirement homes and hunting lodges of a more durable and desirable nature. The Subdivision Regulations contain a significant number of regulations concerning lot size, block size, easements and alleys, platting above the flood plain, and parks and open spaces. A preliminary and final plot approval is necessary before a subdivision plat may be recorded. The regulations require a bond or a lien for the construction of public improvements.

In addition to the Subdivision Regulations, the mobile home regulations of Rio Blanco County, which, again, cover substantially all of the Piceance Creek Basin, are anticipated to be a major safeguard against strip development, shanty-town development in or near an area of oil shale activity, speculative land uses not having proper safeguards towards air and water pollution, and blights on the landscape. The resolution is not intended as a device towards discrimination on account of race, national origin, or economic status. The planning commission expects the development of mobile home parks, but anticipates that the mobile home parks will be of the best quality obtainable. The present mobile home park regulations, which are anticipated to be reviewed and modernized within the next twelve months, contain the following requirements, among others:

a. Minimum size of five acres.

b. Location on a well-drained site.

c. A common open area of not less than two hundred square feet per mobile home space.

d. No less than three thousand square feet per each mobile home space.

e. Gravel or paved parking space for one automobile for each mobile home space.

f. All driveways and walkways hard-surfaced and lighted at night.

g. Cold water tap for each space.

h. Service buildings.

i. Public sewer system. Trapped sewer line for each space.

j. Fire extinguishing equipment.

By these regulations it is anticipated that the development of mobile home parks will be orderly and of a high quality.

At the time the subdivision regulations and mobile home regulations were being considered, the road and highway network of Rio Blanco County was being studied by the Planning Commission. Access from Meeker, the county seat, into the Piceance Creek Basin and access to the oil shale in the basin were thoroughly considered. As a result of these studies, it was recommended to the Board of County Commissioners of Rio Blanco County that the county road along Piceance Creek, an improved gravel road, be brought to state highway standards and paved. The County Commissioners followed this recommendation and more than one million dollars was spent by the county on the acquisition of rights-of-way, engineering, construction and paving of this highway which is now paved from its terminus at Rio Blanco on State Highway 13 to the other terminus at the White River at the mouth of Piceance Creek on State Highway 64. Direct access from Meeker into the shale area has been delayed until the pattern of oil shale development became clear. Since 1965 the interest or excitement about shale development has diminished, and no significant road development in the area has followed completion of the Piceance Creek Highway.

Pursuant to a county zoning plan developed by the Planning Commission, the entire Piceance Creek Basin, as well as nearly all the rest of the county, was zoned A-Agricultural. This zoning classification permits, generally, farm buildings, dwellings, churches, guest ranches, public recreation areas, public utilities, schools, vacation homes and cabins, and certain specified temporary uses. The uses allowed with planning commission approval include cemeteries, commercial feed yards, slaughterhouses, mines, quarries, sand and excavation pits, and mineral research sites and tank batteries. Any use is subject, of course, to prohibitions on air or water pollution, compatibility with existing uses, scarring of land, and restrictions on unsightly aspects, odors, and noise. It should be emphasized that mineral research sites are allowed as temporary uses in the Piceance Creek Basin without a change in the zoning plan if they do not create air or water pollution, and if they satisfy the requirements of the zoning resolution.

As in other zoning plans, an H-I, Heavy Industrial zone is provided, upon application to the planning commission, but there is a provision against air or water pollution, and the location of the zone is qualified by the remoteness of the area, the proximity to towns, requirements for water and sewage systems, and various other conditions. Throughout the zoning plan there is a severe restriction on signs and outdoor advertising devices, as well as off-street parking requirements. The zoning resolution also contains restrictions as to dumping of industrial waste material, with additional requirements that the dumping of waste shall not create air or water pollution, and shall not unnecessarily scar the land or leave denuded slopes, uncovered soil piles, scars upon areas of natural beauty, or unguarded holes or pits.

The planning commission employs a zoning enforcement officer, and meets regularly, but principally upon notice of business coming before the commission.

8.2 PUBLIC FACILITIES.

The present public facilities in Western Colorado, generally, can support a population well in excess of the present population. To be sure, some dislocations will occur, but the development of the infrastructure is quite advanced.

Rio Blanco County, with its tax base primarily supported from the two largest oil fields in Colorado, operates with a relatively secure public revenue source. Because of this secure public fund situation, and aided by past programs of the Colorado Department of Highways and the Colorado General Assembly, and because of the public interest of its citizens, the community is well provided with public facilities.

The school systems for Rangely and Meeker are outstanding, and their physical plants can accommodate an influx of students without strain. County school administrators have devoted much time and thought to the problems which may accompany the advent of an oil shale industry. The present system has been designed to accommodate a 50 percent increase in school population without additional buildings. The county high school plants have been constructed with a view to ultimate expansion so that key elements in the improvement -- heating, gymnasium, food service, auditoriums -- can accommodate a much larger school population. Expansion of classroom facilities has been planned for both temporary (construction) and permanent industrial populations, with plans for temporary classroom additions to accommodate the former and permanent additions for the latter. The school system has established a reserve of $200,000 to meet temporary expansion contingencies. Local tax revenues from oil shale development will adequately provide for long term school building requirements. Public Law 815 and Public Law 874 may aid in solving interim requirements. The county school transportation system already covers all areas which would be affected by oil shale development; the purchase of vehicles is all that is needed to expand its capacity.

Each community has a hospital of more than 20 beds. Each hospital is well supported and adequately staffed and equipped. The county roads are paved and the communities each have adequate water systems and sewage disposal systems.

Among Meeker's charitable endowments is the Freeman E. Fairfield Meeker Charitable Trust, a fund of two million dollars, the income of which is devoted annually to charitable, educational, scientific, literary, and religious purposes in the Meeker community. A library adequate for the needs of the community is now being planned. The parks, churches, community and health facilities all combine to make Meeker a town in which there is increasing development of homes by retired persons and professionals anxious to leave the cities. Rangely supports a junior college through the oil tax revenues and is a center for mineral development in the region. Rangely, Rifle and Meeker each have paved, lighted airports, and the highway communication in the region is satisfactory. The nearest airports of jet capability are at Grand Junction and Hayden, but the F.A.A. has current surveys underway for construction of an airport of jet capability at Meeker.

IX. LEGISLATIVE AND ADMINISTRATIVE PROTECTION OF THE ENVIRONMENT

Pursuant to federal law, the State of Colorado has adopted comprehensive water and air pollution control legislation, which would be applicable to oil shale development in the Piceance Basin. With respect to land reclamation, prospective mining operations would be subject to both applicable federal regulations and state mine surface reclamation legislation.

9.1 WATER POLLUTION CONTROL.

Following passage by the federal government of the Water Quality Act of 1965, the Colorado General Assembly adopted the Water Pollution Control Act of 1966, providing for ". . . the prevention, abatement and control of the pollution of the waters of this state . . ." (Colorado Revised Statutes 1963, §67-28-1, et seq.) The Act created as a division of the Public Health Department a State Water Pollution Control Commission consisting of eleven members. The commission was charged with adopting and promulgating water quality standards that would apply to all waters of the state, and in so doing to refer to the standards acceptable under the criteria established by the Federal Water Pollution Control Act as minimum levels. Enforcement was vested in the Division of Administration of the Public Health Department.

In 1967 the Act was amended to allow the Commission to set effluent standards when stream standards have been exceeded. (Colorado Revised Statutes 1963, §67-28-8(2)(a), as amended). In 1968 the Commission was given greater independence and removed as a division of the Public Health Department. A copy of the Colorado Water Pollution Control Act, as amended, is attached as Appendix 9.1.

Pursuant to its authority, the Commission has adopted water quality standards that apply to all waters of the state and also water quality standards that apply to waters specially classified by the Commission, it being recognized that, due to variable factors, different standards of quality will apply to different waters of the state or to specific segments of such waters. (Colorado Revised Statutes 1963, §66-28-8.) A copy of the water quality standards for Colorado and the classification of the White River as adopted by the Water Pollution Control

Commission are attached as Appendix 9.2. None of the streams in the Piceance Creek Basin have been specially classified by the Commission. Therefore, the basic standards applicable to all waters, both public and private, including natural and artificial lakes and reservoirs, whether classified or not, would apply to waters in the Piceance Creek Basin. In connection with an oil shale leasing program, tributaries of the White River such as Piceance, Yellow, and Douglas Creeks should be classified so that the adoption of specific water quality standards for the designated class would become applicable in addition to the general, basic standards.

As defined in the Act, "waters of the state" mean all waters within the jurisdiction of Colorado, including all bodies or accumulations of water, surface and underground. (Colorado Revised Statutes 1963, §66-28-2(g).) In 1970 the Colorado Legislature adopted additional legislation which provides that "it shall be unlawful for any person to discharge, deposit, generate, or dispose of any radioactive, toxic, or other waste underground in liquid or explosive form" unless the Water Pollution Control Commission, after investigation and hearing, shall have first found beyond a reasonable doubt that there will be no resulting pollution; or that the pollution, if any, will be limited to waters in a specified limited area from which there is no risk of significant migration and that the proposed activity is justified by public need. In the latter case, the Commission may grant a written permit for the proposed activity. (Colorado Revised Statutes 1963, §66-28-9(2)(a).)

The Commission has adopted rules and regulations for subsurface disposal systems, a copy of which is attached as Appendix 9.3. In accordance with these rules and regulations, the Shell Oil Company was granted a permit in 1970 to dispose of waste waters underground in connection with its in situ operations in Section 29, Township 1 South, Range 97 West, 6th P.M., in Rio Blanco County.

The Commission has the power to require and issue or deny licenses, permits, or other written authorizations for the construction and use of septic tanks (Colorado Revised Statutes 1963, §66-28-8(5)), and has prepared rules for site location approval for septic tank systems.

Before enactment of the Colorado Water Pollution Control Act of 1966, no state agency was responsible for the control of mine drainage wastes. Working with representatives of the mining industry, the Colorado State Bureau of Mines, and the U. S. Bureau of Mines, the Commission has prepared "Guidelines for the Design, Operation, and Maintenance of Mill Tailing Ponds to Prevent Water Pollution. The Commission has also prepared further guidelines which apply to mine water pollution control, in particular drainage problems which may exist in connection with mining operations. Copies of both these guidelines are attached as Appendix 9.4.

9.2 AIR POLLUTION CONTROL.

Prior to 1970, ambient and emission standards for air pollution control in Colorado were set by statute by the State Legislature. Enforcement and responsibility for the general administration of air pollution control was vested in the Division of Administration of the State Department of Public Health. The ambient standards applied statewide, but emission standards only applied to those areas of the state designated by the division as air pollution control basins.

In 1970, the State Legislature adopted a new Air Pollution Control Act. (Colorado Revised Statutes 1963, §66-31-1, et seq.). This Act created an Air Pollution Control Commission consisting of nine members, one member of the State Board of Health, and eight citizens appointed by the Governor. The commission was charged with the duty of developing and maintaining a comprehensive program for the prevention, control and abatement of air pollution through the state, including a program for control of emissions from all significant sources of air pollution, and the promulgation of ambient air standards for every portion of the state. Ambient air standards may differ for different parts of the state as may be necessitated by variations in altitude, topography, climate, or meteorology. (Colorado Revised Statutes 1963, §66-31-7(b).)

In setting emission control regulations, the commission is to take into consideration a number of factors, including federal recommendations; the extent to which emissions are subject to treatment and control; the seasonal nature of emissions; and whether an emission regulation should be applied throughout the entire state. (Colorado Revised Statutes 1963, §66-31-8.) Standards may be promulgated for special types of facilities, processes, and activities, including industrial and commerical activities, which tend to emit air contaminants as a by-product. (Colorado Revised Statutes 1963, §66-31-8(3).)

The Commission is deemed to have adopted temporary emission control regulations as provided in Colorado Revised Statutes 1963, §66-29-5(2) through (6) until such regulations are modified, altered or revoked. A copy of such emission standards, in addition to the ambient standards contained in the pre-1970 Air Pollution Control Act, are attached as Appendix 9.5.

The Commission is now in the process of studying new emission standards for particulates, smoke and sulphur oxides. Both the Commission and the Air Pollution Control Division of the Colorado Department of Health have promulgated proposed rules and regulations in this regard, copies of which are attached as Appendices 9.6 and 9.7, but none have as yet been adopted. Paragraph G of Section I of the Commission's proposed regulations states that:

> "It shall be the intent of the Commission as rapidly as possible to establish individual emission regulations for the various types of

> industries . . . of the State of Colorado as a basis for further limiting or preventing the degradation of air quality."

The Commission has also adopted new ambient air standards for particulate matter and sulphur dioxide. A copy of such standards is attached as Appendix 9.8. Those standards applicable to areas of the state not included in air quality control areas would be applicable in the Piceance Creek Basin. Proposed ambient air quality standards for carbon monoxide, hydrocarbons, and total oxidents have been promulgated, but not yet adopted. A copy of these standards is attached as Appendix 9.9.

The 1970 Act provides in part that:

> ". . . no person shall permit emission of air contaminants from, or construction or alteration of, any facility, process, or activity, except residential structures, from which air contaminants are, or are to be, emitted through any permanently located chimney, stack, pipe, or other conduit unless and until an 'air contaminant emission notice' has been filed with the division with respect to such emission. A revised emission notice shall be filed whenever a significant change in emissions is anticipated or shall have occurred." (Colorado Revised Statutes 1963, §66-31-12.)

Thus, permission to construct, install, or alter the use of any machine, equipment, or other device as specified by the commission, which may cause or contribute to air pollution in connection with oil shale development must be obtained from the Air Pollution Control Division of the Department of Public Health in accordance with procedures established by the Air Pollution Control Commission. (Colorado Revised Statutes 1963, §66-31-12(4)(a).) A notice of intent to construct, install, or alter such machinery and equipment shall include all relevant plans, specifications, and such other information as is directly or indirectly material to the potentially pollutive effects of such machinery, equipment, or other devices. (Colorado Revised Statutes 1963, §66-31-12(4)(b).)

Local governmental authorities may continue to adopt more restrictive emission control regulations than provided by state law. (Colorado Revised Statutes 1963, §66-31-25.) There are no local air pollution control laws presently in effect which would be applicable to the Piceance Basin.

The Colorado Air Pollution Control Act of 1970 contains provisions for a variance board and variance procedures, judicial review, and enforcement. A copy of the Act is attached as Appendix 9.10.

9.3 FEDERAL REGULATIONS PERTAINING TO MINING OPERATIONS AND LAND RECLAMATION.

As early as 1927, operating and safety regulations governing the mining of oil shale and other nonmetallic minerals were adopted by the Department of Interior. (30 Code of Federal Regulations, Chapter II, Part 231.)

The purpose of these regulations is to assure that mining operations conducted by a lessee will be conducted in accordance with approved methods to prevent waste, damage to mineral-bearing formations, and injury to life or health, and provide for safety and welfare of employees. (30 Code of Federal Regulations Section 231.4.)

The regulations provide that prior to the beginning of actual commercial mining operations maps and plans showing the proposed mining methods and the plant layout be submitted to the District Mining Supervisor for approval. (30 Code of Federal Regulations

Section 231.5.) Although the regulations relate primarily to mining methods and safety measures, a requirement was made that a lessee provide for the disposal of waste rock from mines, material removed in hydraulic or strip mining operations, the sludge from a mill, the brines from a plant, and other refuse so that such materials would not become a nuisance or obstruction to public travel, any private or public land or stream, or in any manner occasion private or public damage. (30 Code of Federal Regulations Section 231.25.)

A copy of the regulations contained in Part 231 is attached as Appendix 9.11.

In 1969, the Department of Interior adopted regulations relating to surface exploration, mining and reclamation of lands. (43 Code of Federal Regulations, Subtitle A, Part 23.) These regulations stated that:

> ". . . The public interest requires that, with respect to the exploration for, and the surface mining of, such minerals, adequate measures be taken to avoid, minimize, or correct damage to the environment - land, water, and air - and to avoid, minimize, or correct hazards to the public health and safety."

The regulations contained in Part 23 provide for the protection and conservation of nonmineral resources during operations for the discovery, development, surface mining, and on-site processing of minerals under permits, leases, or contracts issued pursuant to the Mineral Leasing Act of February 25, 1920, as amended. (43 Code of Federal Regulations Section 23.2.) No person shall, in any manner or by any means which will cause the surface of lands to be disturbed, explore, test, or prospect for minerals subject to disposition under the Mineral Leasing Act without first obtaining a permit, lease, or contract. (43 Code of Federal Regulations Section 23.4.) In connection with such application a technical examination of the prospective surface exploration and mining operations is made by designated federal officials. Based upon the technical examination, the District Bureau of Land Management manager shall formulate general requirements which the applicant must meet for the protection of nonmineral resources during the conduct of exploration or mining operations and for the reclamation of lands or waters affected by exploration or mining operations. (43 Code of Federal Regulations, Section 23.5.)

Before surface mining operations may commence, the operator must file a mining plan with the Regional Mining Supervisor of the Geological Survey and obtain his approval of the plan. (43 Code of Federal Regulations, Section 23.8.) An operator is required to file a performance bond and submit to certain inspection and report requirements. (43 Code of Federal Regulations Section 23.9, Section 23.10.)

A copy of the regulations contained in Part 23 are attached as Appendix 9.12.

9.4 STATE MINE SURFACE RECLAMATION LEGISLATION.

In 1969, the Colorado Legislature enacted amendments to the mining laws of Colorado which require proper stabilization of surface areas disturbed by mining and related activities. Inspectors of the Colorado Bureau of Mines have the duty to examine all ore mills, sampling works, smelters, metallurgical plants, rock and stone quarries, clay pits, tunnels, sand and gravel pit excavations and plants, and mines in this state of whatever kind or character. Specifically, they are to examine the surface areas disturbed or affected by any operations upon properties or sites and the methods of stabilization, including vegetation if necessary and practical, employed in or on such areas to prevent landslides, floods, or erosion. (Colorado Revised Statutes 1963, 92-32-5(1), as amended.)

In addition to inspection and enforcement provisions, the 1969 legislation provided authority for stabilization agreements between mine operations and the Commissioner of Mines. A copy of these amendments as contained in Senate Bill No. 189 is attached as Appendix 9.13.

Guidelines have been developed and adopted by the Colorado Bureau of Mines as a part of its efforts to implement the 1969 amendments. A copy of these guidelines, which have been approved by the U. S. Bureau of Mines, is attached as Appendix 9.14.

The purpose of the guidelines is to provide mine operators with the information they require in order to comply with the stabilization requirements of the law. One of the key provisions of the guidelines is that the Commissioner of Mines may require the posting of a performance bond, conditioned upon the faithful performance of the stabilization work required by order of the Commissioner or inspector or by the terms of an agreement between the Commissioner and a mine operator.

Both the cost of a performance bond and the cost involved in required stabilization work which might be required by the Bureau of Mines would be necessary expenses incurred in the mining and development of an oil shale facility in the Piceance Basin.

9.5 SUMMARY.

In summary, effective regulatory air and water pollution control commissions have been established in Colorado. Both the State of Colorado and the Federal government have adopted legislation and regulations pertaining to mine surface reclamation. Standards of air and water quality and guidelines governing specific mine water and reclamation problems have been promulgated. In connection with an oil shale leasing program, however, the air and water pollution control commissions, the Colorado and U. S. Bureaus of Mines, and other relevant agencies should review the existing standards and guidelines as they relate to industrial development in the Piceance Creek Basin, and adopt such specific or additional standards, guidelines or other regulatory measures applicable to such development as may be necessary or required to assure adequate protection of environmental values.

X. ECONOMICS OF ENVIRONMENTAL PROTECTION

Determination of the incremental costs attributable to environmental protection is difficult because most of the steps which may be defined as environmental protection steps would be taken, at least in part, during the course of normal operation. As an example, the methods used to prevent dust pollution of the air would normally be required for the health, safety, and comfort of the employees, and steps taken to prevent pollution by contaminated water effluents would often be taken to conserve water for use in the operations. The following list shows some of the industrial elements which may be considered, either in part or totally, as environmental cost factors in a typical industrial oil shale operation. The list is not necessarily complete, and some of the items may be only very small cost factors, but the list will illustrate the types of operations which are being considered in evaluating the environmental aspects of an oil shale industry.

- Mine

  Location - near good disposal area,
  avoid valuable environment
  Subsidence control
  Saline water disposal

Water flow control
Overburden disposal and restoration (surface mine only)
Mine pit restoration (surface mine only)

- <u>Crusher</u>

  Enclosure
  Water sprays
  Water consumption
  Dust collection
  Conveyor covers

- <u>Raw Shale Transport and Storage</u>

  Water sprays
  Water consumption
  Dust collection
  Conveyor covers
  Surge bin covers
  Storage pile covers

- <u>Retort</u>

  Dust collection - raw shale feeders, preheat system vents, ball system vents, retort residue cooling and wetting
  Dust cyclones
  Dust scrubbers
  Dust scrubber slime system
  Aerial coolers to conserve water
  Water consumption

- <u>Pre-Refining</u>

  Process fuel sulfur removal
  Aerial coolers to conserve water
  Sour water treatment
  Skim pit
  Storage tank dikes
  Storage tank covers and floating roofs

- Processed Shale Disposal

  Conveyor covers
  Upper retention dam
  Water diversion system
  Wetting water consumption
  Compaction equipment
  Compactive effort
  Lower retention dam
  Water recycle system
  Topping
  Revegetation
  Mine disposal
  Disposal area fencing

- Offsites

  Plant area fencing
  Road paving and drainage
  Plant area drainage collection
  Power lines
  Gas lines
  Synthetic crude oil pipeline
  Water line incremental increase
  Surface restoration

- Environmental Control Monitoring

  Air pollution
  Water pollution
  Wildlife studies
  Vegetation studies

Costs for the elements listed above have been estimated on the assumption that the environmental protection measures discussed in this report will meet anticipated environmental control standards. The anticipated standards are based on a knowledge of effective standards in various pollution control centers in the United States, as well as in Colorado. If, however, standards are changed substantially from those assumed for the purposes of this report, costs could change consequentially.

Using the basis described above, the environmental cost increments for an underground or surface mine with retort with upgrading facilities described elsewhere in this report and listed above have been estimated as approximately 7 percent of all capital costs. On the same basis, the operating costs (including depreciation, but excluding Federal income tax, cost of capital, and return on investment) were also estimated as approximately 7 percent of total costs.

XI. RECOMMENDATIONS

Although this report and its findings lead to the conclusion that the environmental impact of a first generation oil shale industry in the Piceance Creek Basin can be evaluated and controlled, continuing studies are needed to establish and maintain current environmental protection methods which shall meet the changing demands of a developing oil shale industry. Therefore, the Committee recommends the establishment of a joint advisory committee composed of members of the Secretarial Oil Shale Task Force and representatives of the various state and local agencies concerned with oil shale development and representatives of industry and conservation groups.

The function of the joint committee shall be to act in a technical advisory capacity, on a continuing basis, to the Secretary of the Interior and to the Governor of the State of Colorado, and to Federal and State agencies charged with environmental protection responsibilities. In order to supplement existing knowledge in important areas of concern, the joint committee should conduct special studies to include, among others, the following subjects:

11.1 UNDERGROUND WATER.

The presently available information relating to underground water in the Piceance Creek Basin is insufficient to permit evaluation of the amount and quality of water that will be encountered in certain sites and mining horizons. Accordingly, a study group should compile and analyze all existing material relevant to the location, volume, qualities, flow rates, sources, and movements of underground water in the basin.

11.2 SURFACE WATER.

Although it appears that sufficient water can be made available to support a sizeable oil shale industry, it is possible that the water supply could ultimately limit the size of the industry. Thus the Committee recommends that studies be conducted to supplement present knowledge of sources, quantities, and quality of water available for use by an oil shale industry. Such knowledge will permit assessment of the long term availability of water and its effect on an oil shale industry, and will provide a sound basis for evolving a water management plan consonant with the optimum regional development.

11.3 WILDLIFE AND VEGETATION.

The current knowledge of revegetation and of soil characteristics of retort residue should be supplemented by cooperative study, utilizing the expertise and resources of personnel in industry, universities, and Federal and State agencies for wildlife, agriculture, forestry, and soil conservation. The effort should be directed toward establishing preferred procedures for restoring, or compensating for loss of, wildlife habitat. Measures have been recommended by Dr. Fred Glover of the Fort Collins Wildlife Cooperative Unit and by Mr. Harold E. Boeker of the Bureau of Sports Fisheries and Wildlife (Appendix 11.1).

11.4 REGIONAL DEVELOPMENT.

Cooperative regional studies of land use and community development should be conducted to insure an orderly and integrated transition to the more populous and industrialized community of a mature oil shale industry.

11.5 ENVIRONMENTAL IMPACT STUDY BY AN INDEPENDENT CONSERVATION ORGANIZATION.

An independent conservation-oriented entity should be retained to conduct an environmental inventory and impact study of the type and scope that has been of proven value in guiding other industrial developments in the Rocky Mountain area.