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CANDIDATE AREA EVALUATION REPORT
LOW-LEVEL RADIOACTIVE WASTE DISPOSAL
COLORADO

by
Wynn Eakins
Walter R. Junge
Jeffrey L. Hynes

Colorado Geological Survey
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State of Colorado

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Performance Objectives and Technical Criteria, Low Level Radioactive Waste Disposal.......... A-1

1.0 Executive Summary

This report describes the procedure and results of a regional search for areas that appear to be suitable for the disposal and long-term containment of low-level radioactive wastes. This search identified six (6) candidate areas within Colorado: Central Plains, Central Foothills, Southern Foothills, Grand Valley, Lower Gunnison, and Grand Hogback. Each of these areas contains several potential sites that may be suitable for waste disposal operations. A single potential site, herein termed the representative site, was selected from each of the candidate areas. The location of the candidate areas is shown on Figure 1, and their accompanying representative sites are shown in Figures 5, 9, 13, 17, 21 and 26.

A comprehensive process was used to identify and select the candidate areas and representative sites. This process was based upon a detailed technical analysis of geologic, geohydrologic, and geotechnical parameters related to waste disposal. Primary emphasis was given to defining natural mechanisms that would promote the long-term isolation of the wastes from man and the environment. This included the identification of areas containing thick, relatively impermeable shale that are geomorphicaly stable and contain little, if any, useable ground water. All candidate areas appear to have sites that are suitable for the disposal of low-level radioactive waste. A summary of the major characteristics of these areas is as follows:

<u>Central Plains Candidate Area</u>

Summary of Technical Evaluation:

° Host Rock - Pierre Shale
Thickness 3000 to 6000 feet
Permeability 1 X 10^{-7} centimeters per second or less

° Geomorphic Stability - Low to moderate susceptibility to erosion and mass wasting in most areas, except in the vicinity of drainages.

° Ground Water - Dakota Sandstone is the first underlying bedrock aquifer, depth ranges from about 3000 to 6000 feet, poor quality; minor alluvial aquifers are present in the area.

° Surface Water - Ephemeral streams only and no large bodies of water. Drainage divide separates creeks flowing toward South Platte and Arkansas Rivers.

Summary of Environmental Evaluation:

° Population - Remote from major cities; Limon and Hugo are the primary populated areas in the vicinity, both are near the boundary of the area.

° Land Use - Primarily grazing and non-irrigated farming, some prime irrigated farmland, less than 10% of land state-owned.

° Transportation - I-70 is the primary road, running east-west through center of the area. U.S. Highway 36 and 40, and State Highway 71 provide access to different parts of area. Union Pacific and Chicago Rock Island and Pacific Railroads follow I-70 and U.S. Highway 50 through the area.

Central Foothills Candidate Area

Summary of Technical Evaluation:

° Host Rock - Pierre Shale
Thickness 2000 to 3000 feet
Permeability 1 X 10^{-7} centimeters per second or less

° Geomorphic Stability - Low to moderate susceptibility to erosion and mass-wasting in most areas, except in the vicinity of drainages.

° Ground Water - Dakota Sandstone is the first underlying bedrock aquifer, depth ranges from over 2000 to over 3000 feet, unknown quality; alluvial aquifers in the drainages.

° Surface Water - Fountain Creek flows southward into the eastward-flowing Arkansas River in the vicinity of the candidate area. All streams within the candidate area are ephemeral, and flow into either Fountain Creek or the Arkansas River.

Summary of Environmental Evaluation:

° Population - Colorado Springs and Pueblo are in the vicinity of the candidate area, but potential sites are relatively remote from these population centers.

° Land Use - Primarily grazing, with some non-irrigated farming. Irrigated farming along east side of Fountain Creek near area. 30% of land state-owned.

° Transportation - I-25 is the primary road, running in a north-south direction west of the principal area, between Colorado Springs and Pueblo. Atchison Topeka and Santa Fe, and Denver Rio Grande Western Railroads follow I-25 (on east side) in this area.

Southern Foothills Candidate Area

Summary of Technical Evaluation:

° Host Rock - Pierre Shale
Thickness 0 to 2100 feet
Permeability 1 X 10^{-7} centimeters per second or less

° Geomorphic Stability - Low to moderate susceptibility to erosion and mass wasting in most areas, except in the vicinity of drainages.

- Ground Water - Dakota Sandstone is the first underlying bedrock aquifer, depth ranges from 100 to 2500 feet, poor quality; minor alluvial aquifers.

- Surface Water - Cucharas and Purgatoire Rivers flow in generally eastward direction across the area. Other streams are ephemeral. Numerous small lakes.

Summary of Environmental Evaluation:

- Population - Walsenburg, Aguilar and Trinidad are the primary population centers, all on the western side of the candidate area.

- Land Use - Primarily grazing, with some irrigated farmland, partly prime farmland, along the Purgatoire River. 5% of land state-owned.

- Transportation - I-70 is the primary road, running generally northwest-southeast along western side of most of area, then west of area from Trinidad to the New Mexico state line. Served by 3 major railroads: D&RGW, Colorado and Southern and Atchison Topeka and Santa Fe.

Grand Valley Candidate Area

Summary of Technical Evaluation:

- Host Rock - Mancos Shale
  Thickness 0 to 3000 feet
  Permeability 1 X 10^{-7} centimeters per second or less

- Geomorphic Stability - Low susceptibility to erosion and mass wasting in most areas, except in the vicinity of drainages.

- Ground Water - Dakota Sandstone is the first underlying bedrock aquifer, depth ranges from 100 to 3000 feet, poor quality; some minor alluvial aquifers in the area.

- Surface Water - Colorado River is the primary source of surface water, flowing generally southeast to northwest along southwest margin of the candidate area.

Summary of Environmental Evaluation:

- Population - Grand Junction and Fruita are the primary populated areas in the vicinity, both near I-70 and the Colorado River along the southwest margin of the candidate area.

- Land Use - Primarily grazing, except south of the Highline Canal where irrigated agriculture is prevalent (some prime irrigated farmland). 70% of land BLM controlled.

- Transportation - I-70 is the primary highway, running generally along the Colorado River from Grand Junction to Mack, and diverging as much as 6 miles north of river. Denver Rio Grande and Western (D&RGW) Railroad follows the Colorado River.

Lower Gunnison Candidate Area

Summary of Technical Evaluation:

- Host Rock - Mancos Shale
  Thickness 0 to 3000 feet
  Permeability 1 X 10^{-7} centimeters per second or less

- Geomorphic Stability - Low susceptibility to erosion and mass wasting in most areas, except in the vicinity of drainages and in areas of steep slopes near Grand Mesa.

- Ground Water - Dakota Sandstone is the first underlying bedrock aquifer, depth ranges from 100 to 3000 feet, poor quality; some minor alluvial aquifers in the area.

- Surface Water - Gunnison River is the primary source of surface water; also present are several creeks and reservoirs. Gunnison River flows to northwest along western side of candidate area, to confluence with the Colorado River near northwest part of area.

Summary of Environmental Evaluation:

- Population - Whitewater and Grand Junction are the primary populated areas in the vicinity, both are along the Gunnison River and U.S. Highway 50.

- Land Use - Primarily grazing, limited agriculture. 60% of land BLM controlled.

- Transportation - U.S. Hwy. 50 runs southeast-northwest along western side of area, generally 3-4 miles east of the Gunnison River, joins I-70 in Grand Junction. D&RGW Railroad follows the Gunnison River along the margin of the candidate area.

Grand Hogback Candidate Area

Summary of Technical Evaluation:

- Host Rock - Wasatch Formation
  Thickness 0 to 5000 feet
  Permeability - variable, depending upon presence of sandstones

- Geomorphic Stability - Many areas have high or moderate susceptibility to erosion and mass wasting, but some specific sites have lower susceptibilities.

° Ground Water - Middle member of Wasatch Formation is potentially the first underlying bedrock aquifer, variable depth and quality; alluvial aquifers primarily in vicinity of Colorado River.

° Surface Water - Colorado River is the primary source of surface water, flowing generally southwestward through center of candidate area. Also several creeks, all of which flow into the Colorado River.

Summary of Environmental Evaluation:

° Population - Silt, Rifle, Parachute, Battlement Mesa and DeBeque are the primary populated areas in the vicinity, all along I-70 and the Colorado River.

° Land Use - Primarily grazing, with some irrigated agriculture (partly prime farmland) along the Colorado River. 30% of land BLM controlled.

° Transportation - I-70/U.S. Hwy. 6 is the primary road, running generally along the Colorado River. D&RGW Railroad closely parallels the highway/river.

Representative sites from each of the candidate areas were chosen and evaluated by a grading matrix (Tables 1-6). The numerical rating matrix is designed to evaluate the key technical factors that are important to successful siting of a low-level waste repository. Paramount in these factors are the geological and hydrogeological characteristics of the representative site. Individual site scores and relative technical rankings are as follows:

Two Road	109
Clifford	108
Wigwam	108
Rugby	105
Estes Gulch	94
Cheney Reservoir	84

The matrix scores could range from 0 (an unsuitable site area) to a maximum of 120 (a perfect site area). The Two Road, Clifford, Wigwam, and Rugby sites all rank very high and should be considered as having a very high potential for safe, long-term disposal of radioactive wastes. The other two sites, Estes Gulch and Cheney Reservoir rank lower because of their geologic settings. Special investigations during any future studies should fully evaluate the suitability of these sites and possible methods to mitigate potential problems.

2.0 Introduction

2.1 Purpose of Candidate Area Evaluation Report

The basic framework for siting and licensing a low-level radioactive waste facility in Colorado is provided through the Rocky Mountain Low-Level Radioactive Waste Compact. The Rocky Mountain Compact, formed in 1982, identified Colorado as the host state for a new disposal facility. In 1986, the Colorado Department of Natural Resources entered into an agreement with the Governor's Office to cooperate in the evaluation of alternate areas for the disposal of low-level radioactive waste. This evaluation, part of a larger project conducted by the Governor's Office to develop a low-level waste program, is intended to meet the needs of the Rocky Mountain Compact in the search for a state-of-the-art disposal facility.

The purpose of this study is to identify areas in Colorado which are technically suitable for the disposal of low-level radioactive waste materials. The primary objective in locating a disposal site is to assure the control of these materials in a safe and environmentally sound manner. To this end, the Candidate Area Evaluation Report describes areas in Colorado that have technical aspects conducive to long-term containment of the wastes. This report presents the process by which candidate areas were selected and evaluated. In addition, background data and information regarding representative sites within these areas are described in this report.

The Candidate Area Evaluation Report is intended for use by the State of Colorado, Rocky Mountain Compact, and industry. This report should not be considered a comprehensive, final study, but should only be considered as the initial step in the site selection process. The representative sites described in this report are thought to be descriptive of sites in the candidate areas. Other sites, on both public and private land, are present within these areas and may be suitable for waste disposal activities upon further detailed study.

2.2 History of Rocky Mountain Compact

The Rocky Mountain Low-Level Radioactive Waste Compact was formed over the course of a year, with final agreement on the language of the compact agreed to in 1982. Colorado adopted the compact into law in 1982 and New Mexico, Nevada and Wyoming joined the compact in 1983. Other states eligible to join the compact are Arizona and Utah.

A strategy and plan for siting and licensing a waste disposal facility are included in the Rocky Mountain Compact's authority. This plan includes the implementation of a site selection process by which a technically feasible site may be selected. This report should be considered as the initial step in this process.

2.3 Siting Objectives and Technical Criteria

Low-level radioactive waste contains artificially produced radionuclides. These radionuclides could be a source of increased exposure to humans if dispersed by natural forces. The philosophy expressed by Lush and others (1978) is worth considering as to the long-term containment of low-level radioactive waste.

> "The development of a long-term waste management philosophy requires the acceptance of a basic set of management criteria. Our society's approach has, as its basic tenets, that the present generation of waste managers should leave the wastes in such a manner that there is no foreseeable threat to future generations and future generations will not have to be involved in the care of the wastes. Implied is that the future bleed rate of contaminants from waste management sites should not exceed present regulatory levels, and not rely on continued monitoring to demonstrate that fact."

Radionuclides must be controlled for thousands of years by selecting disposal sites that optimize natural geologic, hydrologic, meteorologic, and geochemical conditions. To achieve this containment, the Colorado Department of Health (CDH) recently promulgated low-level regulations as Part 14 of their Rules and Regulations Pertaining to Radiation Control (24-11-101 et.seq. CRS 1982). These rules and regulations are equivalent to the appropriate federal regulations and must be adhered to during siting design operation and closure of a low-level waste disposal site. Siting, the critical first step in developing a waste disposal facility, must follow the performance objectives and technical criteria in these rules and regulations. These objectives and criteria are included in Appendix A within this report.

2.4 Description of Candidate Area Selection and Evaluation Process

As stated in the state's performance objectives and technical criteria (Appendix A), land disposal facilities must be sited, monitored, designed, constructed, and closed so exposures to humans are within the regulatory limits. In the selection of a disposal site, primary emphasis is to be given to isolation of the waste materials and associated contaminants from humans and the environment for both the short and long-term without ongoing, active maintenance. To accomplish long-term control, primary consideration is given to identification of optimal siting features and meeting the technical criteria.

These objectives and technical criteria formed the foundation for the present study. Typically, a site selection process involves three phases: I) screening, II) evaluation, and III) confirmation. This study assessed Phase I (State Screening) and Phase II (Candidate Area Evaluation). However, Phase III was not conducted for any of the candidate areas and confirmation of the areas by specific field investigations was not a part of this study. Additional, site specific data must be collected to verify the site conditions in the areas described herein so that detailed evaluations can be performed. Such evaluations will be necessary prior to the submittal of any license application.

Phase I: Screening was conducted to eliminate vast areas of the state where the siting and development of a disposal facility could prove to be difficult or where potential transportation problems could cause special concerns. It must be emphasized that acceptable sites may exist in the areas eliminated by this method. If a site is desired in any eliminated area, detailed technical studies should be performed.

The first step in Phase I was to determine the geologic formations that possess acceptable permeability, thickness, and lateral lithologic continuity. These formations should have beds of low or very low permeability that are at least 250 feet thick and are laterally persistent for many square miles. Formations with these characteristics are herein called "suitable formations". Certain other geologic formations in Colorado may in part meet these criteria, but they generally are not as thick, as laterally persistent, or may contain aquifers. These formations are not obvious host formations, but are herein called "possibly suitable formations". In areas where there is insufficient area underlain by "suitable formations", the "possibly suitable formations" become important, and in such cases, received thorough evaluation. Detailed studies may eventually prove that some areas underlain by "possibly suitable formations" do meet the specified siting requirements. Two suitable formations (Pierre Shale of eastern Colorado and Mancos Shale of western Colorado) and one potentially suitable formation (Wasatch Formation in western Colorado) were delineated in the state screening process. Figure 1 shows the location of these formations. Hynes and Sutton (1980) previously performed this first step evaluation, so their work was utilized.

The second step in the Phase I process consisted of identifying suitable transportation corridors so that potential transportation concerns could be minimized. As shown on Figure 1, a 40 mile wide band along the major interstate highway network was selected. Much of this area is also served by various railroads.

The last step in Phase I was the selection of candidate areas within the transportation corridors that are underlain by suitable or potentially suitable formations. All of these areas were evaluated with regard to the following criteria and were eliminated if one or more of the criteria were met.

1) areas of insufficient size,
2) areas subject to extensive river flooding,
3) areas of critical ground water resources or recharge,
4) areas of complex geologic structure (e.g. abundant faulting, folding, or jointing),
5) areas susceptible to geologic hazards that could disrupt the repository (e.g. active faulting, subsidence, unstable slopes, etc.),
6) areas with severe erosion potential or unstable landforms,
7) areas of Quaternary glacial or igneous activity,
8) areas with critical mineral, geothermal, archaeologic, cultural, historic, wildlife, or ecologic resources,
9) areas of critical surface water, springs, or present or planned large bodies of water,
10) areas of concentrated human habitation or future growth areas: towns, subdivisions, and densely populated rural areas,
11) National Parks, National Monuments, Wildlife Refuges, Wilderness Areas, or wild and scenic river areas, or
12) areas of prime, irrigated agricultural lands

Six candidate areas were selected during the Phase I analysis and include the Central Plains, Central Foothills, Southern Foothills, Grand Valley, Lower Gunnison, and Grand Hogback areas (Figure 1).

Phase II: During Phase II the six candidate areas were evaluated with regard to their potential for having one or more disposal sites. The first step in the Phase II process included the analysis of the areas for state or federal lands. All candidate areas contain sufficient disposal sites on public lands such that private land was not further considered in any of the areas.

The second step in Phase II was the evaluation of potential site areas with regard to Criterion 1 of the Performance Objectives and Technical Criteria (Appendix A). Specifically, potential site areas were eliminated based on size of the disposal area, proximity to useable waters, proximity to population, size of the upstream drainage basin, and areas of high erosion or geomorphic instability. Potential sites are shown on the 1:300,000 scale maps for each candidate area (Figures 5, 9, 13, 17, 21, and 26).

The next step was the selection and description of a representative site in each of the candidate areas. These representative sites were selected based upon their overall site suitability with regard to long-term containment of the waste materials. Multiple sites contained in a specific candidate area were not evaluated and compared to each other. These other sites could prove to be acceptable based upon additional technical investigations. It should be emphasized that the site boundaries herein designated are not permanently fixed. Boundaries may be somewhat revised to allow for conflicts related to land ownership, land use, geotechnical aspects, or other factors.

Three 1:24,000 scale maps were prepared to illustrate important features of each representative site and surrounding area. These maps are a surficial geology and slope map, a land use and ownership map and a geologic hazards and constraints map. Figure 4 explains the symbols and abbreviations used on all of the representative site maps.

An explanation regarding the determination of erosion potential and long-term geomorphic stability for the geologic hazards and constraints map may clarify some possibly confusing issues. All land areas are susceptible to some type of erosion, with the exception of areas that are experiencing active deposition. Currently, depositional areas are relatively rare in Colorado. Areas with low or moderate erosion potential generally are protected by a cap of erosion-resistant rock or gravel and do not have through-going drainage systems. These areas are often suitable for tailings disposal, although some specially engineered structures or construction techniques may be needed to assure long-term resistance to erosion.

High erosion potential areas generally have easily eroded material at the surface and may be within through-going, but small drainages. Certain areas with high erosion potential may be acceptable for low-level waste disposal if specially designed protective structures are constructed. A severe erosion potential exists along creeks, streams, and rivers that drain sizable areas and are subject to flash flooding or mainstream river flooding. It is difficult, if not impossible, to design and construct a safe tailings repository in a severe erosion potential area.

The long-term geomorphic stability of an area relates not only to erosion potential, but also to other types of geologic hazards that may disrupt or disturb the area. Because the site selection techniques used in this study eliminate areas subject to most geologic hazards, variance in erosion potential is a key element used in comparing the long-term stability of the potential sites. In general, sites undergoing active deposition or with low erosion potential have good to excellent long-term stability. Areas with moderate erosion potential are believed to have good long-term stability. Moderate or acceptable long-term stability is associated with sites having a high erosion potential that appears to be controllable through state-of-the-art engineering techniques. Other high erosion areas have only poor long-term geomorphic stability, and sites with a severe erosion potential have very poor stability characteristics. In all cases, further detailed studies are necessary to accurately define a specific area's potential for long-term geomorphic stability.

The final step in the process was the geotechnical evaluation and comparison of the representative sites. This evaluation uses a grading matrix that lists major technical factors that should be considered in developing a low-level waste repository. The grading matrix ranks each of the technical factors and weighs each of the factors according to their relative importance. Technical rank is multiplied by the weight to determine the factor score. These scores are then added to obtain a numerical rating for each representative site.

3.0 Eastern Colorado - Potential Disposal Areas

3.1 Overview of Potential Disposal Areas

Eastern Colorado possesses the appropriate combination of geology, topography, climate and isolation from population centers to make specific areas potentially suitable for a low-level radioactive waste disposal facility. Three areas meeting these general siting aspects are located in eastern Colorado. These areas are designated as the Central Plains, Central Foothills and Southern Foothills Candidate Areas (Figure 1). Other areas to the north and northeast of Denver were eliminated because of their proximity to population or water resources, or because of their use as prime agricultural lands.

This section of the report will focus on the description of the regional setting of these areas. This section is followed by a more detailed description of each candidate area along with their representative sites. Specifically, the Central Plains Candidate Area and accompanying Clifford site are described in Section 3.2 (Figure 5); the Central Foothills Candidate Area and the Wigwam site are described in Section 3.3 (Figure 9); and the Southern Foothills Candidate Area and Rugby site are described in Section 3.4 (Figure 13).

3.1.1 Previous Information

Due to the recognized high probability of finding suitable sites for secure waste disposal facilities as well as other specialized activities, numerous studies have focused on eastern Colorado. Of particular interest have been investigations concerning the Pierre Shale, especially where it is exposed at or near the surface. The most recent regional investigations have been oriented toward activities such as hazardous chemical waste disposal and the installation of a major super collider test facility (SSC). The Colorado Geological Survey has been directly involved in these studies.

Much of the regional material found herein is from the SSC study by the Colorado Geological Survey (Rogers and others, 1985) which relied heavily on previous work in the area. This study should be consulted if additional technical details are needed.

3.1.2 General Area Description

3.1.2.1 Location

The three candidate areas in eastern Colorado are located within outcrop areas of the Pierre Shale shown in Figure 1. The three (3) areas of Pierre Shale under consideration in eastern Colorado lie approximately 50 to 70 miles east of the Denver-Colorado Springs Corridor, and in two narrow bands between Colorado Springs and Pueblo and in the Trinidad-Walsenberg area. The Central Plains Candidate Area is located 50 to 110 miles east and southeast of Denver. The Central Foothills Candidate Area is about 20 by 60 miles in dimension, generally between and east of Colorado Springs and Pueblo.

The Southern Foothills Candidate Area is a relatively narrow (10 miles wide and 75 miles long) band extending southeasterly from north of Walsenburg to the New Mexico border.

3.1.2.2 Topographic Setting

All three areas can be characterized as relatively flat lying terrain incised in places with drainage courses with steeper sloped valley sides. In the two central candidate areas the sideslopes tend to gradually flatten away from the drainages onto essentially flat, horizontal surfaces in the interfluvial areas. In the south, the drainage character is more likely to be steep to vertical-sided arroyos with essentially flat, horizontal surfaces between them.

3.1.2.3 Land Use

With the exception of areas adjacent to communities (which have been excluded from actual consideration), the principal land use in these areas is agricultural with the following relative activities in decreasing order: grazing and browsing, dry land farming, and irrigated farming. Additionally, there is considerable oil and gas production in the area east of Denver-Colorado Springs. This is discussed further in the sections that follow.

3.1.2.4 Geology

Stratigraphy: The Pierre Shale occurs at or near the surface in several areas in eastern Colorado which are large enough to be identified as candidate areas for this study (Figure 1). Numerous workers, including Griffitts (1949), Cobban (1956), Gill and Cobban (1961), Tourtelot (1962), Scott and Cobban (1963, 1965), Kitely (1976, 1977, 1978), and Porter (1976), have studied the Pierre Shale in this area. The stratigraphic nomenclature used in this report and illustrated in Figure 2 was modified from these sources.

Within the candidate areas the Pierre Shale can be divided into three members: a Lower, Middle, and Upper Member. Bentonite layers and faunal zones within the Pierre Shale establish time lines throught the formation.

Subdivision of the three members of the Pierre Shale is based upon lithology. All three members were deposited in a marine environment, but the Upper and Lower Members are predominantly shale, silty shale, and siltstone, while the Middle Member (sometimes called the Hygiene Group) consists of a series of sandstone and siltstone layers interbedded with shale and silty shale. Underlying the Pierre Shale in descending order are the Niobrara Formation, Carlile Shale, Greenhorn Formation, Graneros Shale and the Dakota Group (Figure 2).

The Dakota Sandstone Group, generally about 100 feet thick, consists of several thin to thick evenbedded sandstones interbedded with thin gray shales. In general, the sandstone beds thin eastward and the proportion of shale increases slightly eastward. The Dakota Sandstone Group represents the initial dune-beach-shallow marine and transgressional phases of the Greenhorn marine cycle (Kauffman and others, 1969).

The remainder of the Greenhorn marine cycle is recorded in the members of the Benton Formation, which includes the Graneros Shale, the Greenhorn Limestone, and the Carlile Shale up through the Codell Sandstone. A second half-cycle, the transgression of the Niobrara cycle, is recorded in the overlying Juana Lopez Member of the Carlile Shale through the Fort Hayes Limestone of the Niobrara Formation. The cumulative thickness of these sediments ranges from approximately 500 to 800 feet.

The Smokey Hill Member of the Niobrara Formation lies conformably on top of the Fort Hays Limestone. This unit, approximately 600 feet thick, is composed of marly shale with interbedded thin limestone and sandy shale. The Smokey Hill Member and the Pierre Shale were deposited during Lower and Middle Cretaceous time. At that time eastern Colorado was part of a large interior seaway that extended from northwest Canada to the Gulf of Mexico (Gill and Coban, 1966). This seaway was dominated by shallow marine shelf environments with water depths generally less than 300 feet and rarely over 500 feet.

Geomorphology: The South Platte and Arkansas Rivers have incised Tertiary sedimentary rock layers in eastern Colorado. At Denver, the South Platte River has cut downward 1,500 to 2,000 feet to its present level. Three well-formed terrace levels flank the river's floodplain, and remnants of a number of well-formed higher land surfaces are preserved south and east of the river in the Central Foothills Candidate Area. Extending eastward from the mountain front at Palmer Lake, a high divide separates the drainage of the South Platte River from that of the Arkansas River. The Arkansas River has removed much of the Tertiary piedmont deposits and cut deeply into the older Cretaceous marine rocks between Canon City and the Kansas border.

Much of the terrain in the two river valleys has been smoothed by a nearly continuous mantle of windblown sand and silt. Northwesterly winds have transported fine material from the floodplains of the streams and spread it eastward and southeastward over much of eastern Colorado. Well-formed dunes are not common, but aligned gentle ridges of sand and silt and abundant shallow blowout depressions indicate the windblown origin of this cover.

The landscape of the Southern Foothills Candidate Area consists of plains with gently rolling hills, interrupted by anomalous features related to Laramide and Tertiary volcanism. Radiating from the Spanish Peaks west of the area are hundreds of dikes, nearly vertical slabs of igneous rock that filled fractures radiating from the centers of intrusion. Erosion of the sedimentary layers has left many of these dikes as conspicuous vertical walls of igneous rock that project high above the surrounding land surface. Some of these dikes north of Trinidad extend eastward for about 25 miles, almost to the Purgatoire River.

In eastern Colorado, the erosional effects of streams are the most conspicuous features of the landscape, but these are enhanced by the steep tilting of the layered rocks along the western margin and modified by the products of wind action, which have altered the landscape with a wide-spread cover of windblown sand and silt. Volcanism has had a significant affect on the landscape in the Southern Foothills Candidate Area.

Structure: The structural elements of eastern Colorado geology are relatively simple. In general, folds are broad and beds dip only a few degrees. Faulting is not abundant, but some large displacement faults are scattered across eastern Colorado. Such faults may be growth faults that developed as thick layers of soft sediments were being deposited and consolidated. Further investigation of any faults detected in a specific project area is warranted, should further studies be undertaken.

In the Central Plains Candidate Area, bedrock formations generally dip gently (usually less than a few degrees) to the west into the Denver Basin. Numerous small folds are superimposed on this overall westward-dipping structure. Dips are somewhat steeper in the Central Foothills Candidate Area, where a simple monoclinal drape off the Wet Mountains forms the southwest part of the Denver Basin. In the Southern Foothills Candidate Area, structures are also relatively simple, but several folds and faults locally complicate the structure. Dips are generally one to ten degrees westward into the Raton Basin.

Mineral Resources: Oil and gas resources exist in parts of the candidate areas. Numerous oil and gas fields have been discovered within the northern part of the Central Plains Candidate Area (Scanlon, 1983). These include such large fields as Adena, Boxer, Valery, Bobcat, Plum Brush Creek, Peoria, Beaver, Little Beaver, and Badger Creek. Production is from the D & J Sandstones which lie far below the Pierre Shale. Hundreds of oil and gas test holes have been drilled within this area. and over 20 holes per section are present in the most densely drilled regions. Dry holes that were plugged and abandoned are scattered throughout the area.

The Central Foothills Candidate Area contains no currently producing oil or gas fields and the Southern Foothills has very limited oil or gas production.

Construction of a low-level waste disposal facility should not preclude future discovery and production of oil and gas. Test wells can probe the underlying D & J Sandstones by directional drilling. This technique involves planned angle drilling whereby the potential host rocks can be evaluated beneath a disposal facility.

Seismicity: Eastern Colorado is an area of relatively low seismicity. Most earthquakes have occurred in the western two-thirds of the state. The northeastern part of the state has experienced almost no significant earthquake activity during the period of record.

The nearest significant earthquake activity was located in the northeast Denver area. A series of earthquakes ranging up to magnitude 5.3 occurred in this area in the 1960's and 1970's. The earthquakes were apparently triggered by waste disposal into a deep well at the Rocky Mountain Arsenal (Kirkham and Rogers, 1981). Occurrence of similar-sized earthquakes in this area is possible in the future.

Unpublished seismic intensity maps prepared by the Colorado Geological Survey indicate that seismic vibrational energy associated with historic earthquakes in Colorado appears to be fairly rapidly attenuated in eastern Colorado. Thus, any seismic shaking or potential damage that may result from future earthquakes in this area would probably decrease (attenuate) quickly in an easterly direction.

Potentially active faults in Colorado are designated and described by Kirkham and Rogers (1981). No potentially active faults lie within the candidate areas. The nearest faults are located along the flank of the Front Range and near the Arkansas River Valley.

All candidate areas are in the Plains seismotectonic province of Colorado (Kirkham and Rogers, 1981). Within this province maximum credible earthquakes of magnitude 5.5 to 6.0 are thought to be possible, but with a very long recurrence interval.

3.1.2.5 Hydrology

Surface Water: All streams within the eastern Colorado candidate areas are ephemeral with the exception of the Purgatoire and Cucharas Rivers which flow across the Southern Foothills Candidate Area. All streams are within either the South Platte or Arkansas River Basins; the northern half of the Central Plains Candidate Area drains into the South Platte River and the remainder of the drainage from eastern Colorado candidate areas is within the Arkansas River Basin. Lakes and reservoirs are small and few in number throughout the Central Plains and Central Foothills Candidate Areas. Numerous relatively small lakes and reservoirs occur within the Southern Foothills Candidate Area.

Ground Water: The shallow surficial aquifers include three types of aquifers in eastern Colorado: alluvial aquifers, upland gravel aquifers, and eolian aquifers. All three types of aquifers are unconfined. Within the candidate areas these three types of aquifers are the primary sources of ground water. The Pierre Shale yields very little water to wells.

The alluvial aquifers consist of sand and gravel that fill the channel of modern streams and rivers. According to the well records of the Colorado Division of Water Resources, well yields from alluvial aquifers in the candidate areas are commonly several hundred gallons per minute (gpm), with yields sometimes in excess of 1000 gpm. Other wells reportedly yield less than 10 gpm, and a few wells were drilled into areas where the alluvial aquifers were unsaturated.

Little information has been published on the aquifer characteristics of the upland gravel aquifers, which are of limited extent in the candidate areas.

Eolian deposits blanket large parts of the candidate areas. In many places, particularly where they overlie alluvium, these deposits are unsaturated and will not yield any water to wells. Precipitation in these areas filters through the eolian material and enters the underlying alluvium, leaving the eolian material dry. In areas where less permeable formations underlie the eolian material, the infiltrating water may be trapped within the wind-blown deposits and form a localized aquifer. Wells drilled in the eolian materials should yield small amounts of water (less than 25 gpm).

The Pierre Shale is generally considered to be an extremely poor aquifer in eastern Colorado (Bjorklund and Brown, 1957; McGovern, 1964). Nonetheless, a few water wells have been completed in the Pierre Shale. It is widely acknowledged that when an indurated bedrock formation is exposed to the surface it will expand due to release of overburden pressure. Much of this expansion occurs in the form of fracturing, and such fractures may extend from the land surface to depths of about 200 feet. Water may enter and fill these fractures forming a type of shallow groundwater system. It is our interpretation that the wells of 200 feet or less in depth within the Pierre Shale probably obtain their water from such a fracture system or from a weathered zone. These wells generally yield less than 5 to 10 gpm and may become dry during periods of below normal rainfall.

3.2 Central Plains Candidate Area

3.2.1 Previous Investigation

The Central Plains have been studied previously as a potential site for various activities where the properties of the Pierre Shale, the relatively arid climate and the remoteness of the area were considered to be significant advantages. Such activities have included hazardous and radioactive waste disposal and more recently the installation of a super collider test facility. The primary sources of information are Sharps (1980), and Rogers and others (1985).

3.2.2 General Description

3.2.2.1 Location

The Central Plains Candidate Area is shown on Figure 5. It lies along the Pierre Shale outcrop zone in a 40 mile wide corridor with I-70 in the middle and includes portions of Adams, Arapahoe, Elbert, Lincoln, Washington, Kit Carson and Cheyenne Counties. The primary towns within the candidate area are Limon and Hugo.

3.2.2.2 Topographic Setting

The Central Plains Candidate Area is within the Colorado Piedmont section of the Great Plains Physiographic Province. Topographically, the area is divided into two parts on the basis of drainage. The northern half drains northward toward the South Platte River along Beaver, Badger and Plum Brush Creeks. The southern half drains primarily into Big Sandy Creek which feeds the Arkansas River. Some of the easternmost parts of the southern area drain to the South Fork

Republican River. The area is predominately flat to rolling hills with maximum slopes of 15 percent or less, except for some steep-to-vertical stream banks.

3.2.2.3 Land Use and Ownership

Land use is predominantly agricultural. Both irrigated and dry land crops are produced, and much of the marginal land is used for grazing. Almost all of the land is held in private ownership. State lands, consisting of school sections, are fairly uniformly scattered throughout the candidate area, but federal lands are essentially non-existant.

3.2.2.4 Potential Sites

Several alternative and technically feasible sites are present within the Central Plains Candidate Area. These sites possess a combination of favorable characteristics, including: 1) feasibility of a shallow burial within the Upper Pierre Shale; 2) minimization of any possible interactions with surface water or useable groundwater; 3) good proximity to aggregate supplies for construction needs; and 4) excellent location for access to local source areas and the interstate highway system.

Five potential sites are located within the Central Plains Candidate Area (Figure 5). They are Clifford (the representative site), Middlemist, Vega Creek, Big Sandy and Arriba sites. Twenty-one other sites in the area were considered to have suitable formation and slope characteristics, but are not recommended for other reasons. The reasons for eliminating these areas from further consideration were: the proximity of critical alluvial ground water resources (16 sites), significant erosion potential (5 sites), location within 5 miles of a town and insufficient size (less than one square mile)(4 sites each), and potential river flooding, location in the proximity of critical surface water resources and location within sight distance of I-70 (2 sites each). The sites considered are all within the state lands shown on Figure 5.

3.2.3 Technical Evaluation

3.2.3.1 Geology

The Pierre Shale, bedrock in the candidate area, can be divided into three members, Lower, Middle, and Upper. The sandy units within the Middle Member can be traced, by use of geophysical logs from oil and gas wells, from their outcrop in the Fort Morgan area, where they form small, prominent ridges, eastward and southeastward into the subsurface beneath the candidate area. The Middle Member becomes less sandy and more silty from west to east and north to south (Kitely, 1977, 1978; Gill and Cobban, 1961). Within the candidate area the Middle Member consists mainly of siltstone and shale with only minor amounts of sandstone.

Bedrock formations that overlie the Pierre Shale are important to this project because of the possibility of encountering these formations in proximity to some of the possible sites. Formations that underlie the Pierre Shale are of lesser importance, due to their depth and isolation from the zone in which the facility will be developed.

Immediately overlying the Pierre Shale is a coarsening-upward sequence of interbedded sandstone, siltstone, and shale referred to in this report as the Fox Hills-Pierre Transition Zone. This sequence of rocks represents the transition from primarily fine-grained, marine sediments of the Pierre Shale to the coarse-grained, delta front or beach sediments of the Fox Hills Sandstone. The Fox Hills-Pierre Transition Zone, along with the Fox Hills Sandstone and lower part of the Laramie Formation, constitute the important Laramie-Fox Hills aquifer described by Romero (1976) and Robson and others (1981).

The Fox Hills Sandstone consists of one or more massive sandstone units that occur only in the western part of the Central Plains Candidate Area. The non-marine Laramie Formation contains claystone, shale, and siltstone with coal and lenticular sandstones in its lower part. The Arapahoe, Denver, and Dawson Formations are present only to the west of the candidate area. All of these formations were deposited in a continental environment. The Arapahoe Formation consists of claystone and sandstone, while the Denver Formation is predominantly claystone, lignite, siltstone, and sandstone, and is largely derived from andesitic source rocks. The Dawson Formation consists of arkosic sandstone and conglomerate with locally abundant interbeds of claystone and siltstone.

Capping the high plains on the east and north sides of the candidate area are the gravels and sands of the fluvially deposited Ogallala Formation, an important aquifer in the region. Several recently published reports describe the Ogallala and its hydrologic characteristics (Bornman and Meredith, 1983; Bornman and others, 1983, 1984; Weeks and Gutentag, 1981). Abundant, well-rounded granitic, volcanic and sedimentary rock clasts are present in the gravels of the Ogallala Formation. The gravels and pebbly sands form the bulk of the formation, with lesser amounts of interbedded or laterally equivalent fine sands, siltstone, and claystone present. Locally, the coarser beds have been cemented by calcium carbonate or silica, forming resistant "mortar stone" layers. A two to six foot thick layer of dense, hard caliche caps the Ogallala in some areas.

Unconsolidated surficial units of Quaternary age blanket parts of the candidate area. Stream alluvium and gravel deposits up to 250 feet thick are found in the drainages. Older gravel deposits up to about 100 feet in thickness cap pediment-like surfaces. Wind-blown deposits of dune sand and silt, and silty loess deposits blanket many parts of the candidate areas and are up to 130 feet thick.

The Central Plains Candidate Area lies on the east flank of the Denver Basin. In this region the bedrock formations dip gently, usually less than a few degrees, to the west. Small folds are superimposed upon this overall westward-dipping structure.

Mineral resources within the Central Plains Candidate Area are discussed in Section 3.1.2.4. Oil and gas resources are significant in the northern part of the candidate area. Oil and gas produced in the candidate area are generally produced from the D & J Sandstones of the Dakota Sandstone that are several thousand feet below the potential sites.

3.2.3.2 Hydrology

Primary ground water aquifers adjacent to the Central Plains Candidate Area include the Laramie-Fox Hills aquifer, the Ogallala aquifer, and shallow surficial aquifers. Considerable published data are available for the Laramie-Fox Hills aquifer, Ogallala aquifer, and the South Platte River alluvial aquifer. Minimal information has been published on the alluvial aquifers associated with smaller creeks within eastern Colorado candidate areas. Likewise, little information is available on the aquifer characteristics of the Pierre Shale, as well as the underlying aquifer in the Dakota Sandstone.

Thickness of the alluvial aquifers increases gradually from 0 to over 100 feet. Where Beaver and Badger Creeks join the South Platte River, the alluvial aquifers are as much as 200 to 300 feet thick. According to the well records of the Colorado Division of Water Resources, upland gravel aquifers in the Central Plains Candidate Area are probably around 100 feet thick and wells generally yield less than 20 gpm.

It appears from the work by Rogers and Kirkham (1986) that the Upper Shale Member yields very small amounts of water at least locally in the northeast part of the Central Plains Candidate Area near the South Platte River. In this region the water-saturated alluvium in the South Platte Valley is up to 300 to 400 feet thick. It is possible that water within the alluvium is recharging the silty and sandy zones of the Pierre Shale and that hydrostatic pressures force the groundwater to rise updip (southward) within the Pierre Shale. In light of the dry hole in T5S, R56W, and the test holes at the Last Chance site, it seems probable that the silty and sandy zones within the Pierre Shale contain less water in the southern part of the Central Plains Candidate Area than in the north. Additional, detailed hydrologic information is needed before more definitive conclusions regarding the aquifer characteristics of the Pierre Shale can be formulated.

3.2.4 Representative Site Description - Clifford Site

3.2.4.1 General Site Description

3.2.4.1.1 Location

The Clifford site is in section 36, T11S, R53W. It is 28 road-miles from I-70 at the Limon exit. The north and east sides of the section are bounded by well maintained, unpaved roads; the south, by a poorer quality, but serviceable dirt road.

3.2.4.1.2 Topographic Setting

The Clifford site is situated below an escarpment formed by the Ogallala Formation, which is several miles to the east. The general slope of the site is primarily northwestward at two to four percent with short sections of minimum slope of about one percent and maximum slope of six percent (Figure 6). The general area slopes toward Big Sandy Creek, several miles west of the site.

3.2.4.1.3 Land Use and Ownership

The Clifford site is owned by the State of Colorado. Peripheral private ownership is shown on Figure 7.

Land use consists of open range grazing and oil and gas production from the Clifford field. Section 36 lies on the northwestern edge of the Clifford field and there are two producing wells in the eastern portion of the site as approximately shown on Figure 7.

Potential conflicts regarding grazing and oil and gas leases may have to be resolved if it is decided to pursue use of this particular tract.

3.2.4.2 Technical Evaluation

3.2.4.2.1 Geology

Surficial materials at the site consist of weathered Pierre Shale over most of the section. A gravelly, sandy, alluvial terrace remnant caps a northeast-southwest trending ridge in the southeast corner of the section. Sharps (1980) has classified this deposit as Rocky Flats Alluvium. The surficial material in the northwest corner of the site, which is occupied by an intermittent stream, is slightly more silty and sandy than the slope materials to the southeast. This is most likely due to minor contributions of eolian material.

Bedrock beneath the Clifford Site is the Pierre Shale. Total thickness in this region is approximately 4000 feet.

Geologic constraints on and near the Clifford site are shown on Figure 8. These constraints consist of a higher erosion potential in the vicinity of drainages.

3.2.4.2.2 Hydrology

Drainage on this site is northwestward for all but about 50 acres in the extreme southeast corner, where it is to the south.

Three poorly defined drainage courses direct surface flow into a major, intermittent drainage, which traverses the northwest corner of the section. Flow in the major channel is southwestward toward Big Sandy Creek, three to four miles away.

Shallow stock wells are developed in the silty, sandy clay in the channel. These wells represent essentially all the water available on the site. The water lies on top of the impermeable, unweathered shale bedrock probably within 40 feet of the ground surface. A small stock pond just east of the site was dry at the time of the field inspection of the Clifford site (July 15, 1986).

The first potential aquifer below the site is in excess of 4000 feet deep. This depth of intervening shale functions to completely isolate this aquifer from any surface influence. There are no recorded wells producing from the deep aquifers in the vicinity of the Clifford site.

3.3 Central Foothills Candidate Area

3.3.1 Previous Investigation

Little previous work has been done on the geology or hydrology of the area. This is due to the lack of significant mineral deposits and ground water or surface water resources.

3.3.2 General Description

3.3.2.1 Location

The Central Foothills Candidate Area is located in portions of El Paso and Pueblo Counties, generally between and to the east of the cities of Colorado Springs and Pueblo (Figure 9). Most of the area is east of Interstate Highway 25 (I-25). South of Colorado Springs an area of Pierre Shale within the Fort Carson Military Reservation has been excluded from the candidate area; otherwise, the area is defined by all surface or near-surface exposures of the Pierre Shale within 20 miles of I-25 in El Paso and Pueblo Counties.

3.3.2.2 Topographic Setting

The Central Foothills Candidate Area is in the western part of the Colorado Piedmont section of the Great Plains Physiographic Province, near the boundary with the Rocky Mountain Province. The general topographic feature of the area is gently rolling hills dissected by intermittent streams. Two major drainages traverse the candidate area, the eastward-flowing Arkansas River and southward-flowing Fountain Creek. Exposures of the Pierre Shale occur on either side of these major rivers.

3.3.2.3 Land Use and Ownership

The primary land use within the Central Foothills Candidate Area is cattle grazing. Irrigated and non-irrigated agriculture is fairly prevalent in some peripheral areas, particularly along the river valleys. A majority of the land within the candidate area is privately owned, but several large blocks of state land in addition to single sections make the percentage of state land significant. Several large blocks of federal land, including Fort Carson and the Pueblo Army Depot, are in the vicinity of the candidate area.

3.3.2.4 Potential Sites

Three potential sites are located in the Central Foothills Candidate Area (Figure 9). These sites are state-owned land with relatively flat or gently sloping surfaces between intermittent drainages. Some access problems are posed by the limited number of crossings over Fountain Creek which isolates the majority of the area from direct access from I-25.

The Wigwam site is the representative site. The other potential sites are the Williams Creek and Boone Hill sites. For each of the three sites, the location could be adjusted somewhat since the state land ownership is not confined to individual sections. Eight other sites in the area were considered to have suitable formation and slope characteristics but are not recommended for other reasons. The reasons for dropping these areas from further consideration were: the proximity of ground water and surface water resources and location within 5 miles of any town (3 sites each), insufficient size (2 sites), proximity to extensive river flooding and significant erosion potential (1 site each).

3.3.3 Technical Evaluation

3.3.3.1 Geology

The principal geologic unit of interest is, as with the other eastern slope candidate areas, the Pierre Shale. The general description found in Section 3.1.2.4 can be taken as fairly representative of the stratigraphy in the Central Foothills Candidate Area. Thickness of the Pierre Shale ranges from about 2000 to 3000 feet. The dips are somewhat steeper than in the Central Plains Candidate Area, approaching 20 degrees close to the mountain front on the west margin of the area.

Surficial materials consist primarily of old alluvial gravels on surfaces between the major drainages and minor amounts of eolian sands and silts deposited in the valleys. In some cases small amounts of eolium have been incorporated into the recent, fine-grained, alluvial deposits in the intermittent drainages rendering them slightly coarser grained and possibly more permeable.

Structurally, the area's geology is quite simple, consisting of a monoclinal drape off of the Wet Mountain Uplift.

No valuable mineral deposits underlie the candidate area. The nearest oil and gas production, from the Pierre Shale in the Florence-Canon City Field, is about 35 miles to the west. Sand and gravel deposits are only locally of economic significance.

3.3.3.2 Hydrology

All streams within the Central Foothills Candidate Area are ephemeral, and either flow into Fountain Creek or the Arkansas River. Fountain Creek converges with the Arkansas River in Pueblo, so all surface water eventually flows into the Arkansas River.

The Pierre Shale hydrologically isolates the surface of the candidate area from underlying aquifers. The first principal aquifer below the Central Foothills Candidate Area is the Dakota Sandstone. This unit is not penetrated or used in the candidate area due to the extreme depth (2000 to 3000 feet below the surface) and the lack of any significant demand. The quality of water in the Dakota Sandstone is unknown, but is likely very poor and may exceed even livestock standards.

3.3.4 Representative Site Description - Wigwam Site

3.3.4.1 General Site Description

3.3.4.1.1 Location

The Wigwam Site is located in south-central El Paso County, approximately 20 miles southeast of Colorado Springs and 20 miles north of Pueblo. Fountain, 10 miles northwest of the site, is the nearest town. The site is within section 10, T17S, R64W (Figure 10). Access to the site is via I-25 to the Buttes exit, north one mile to a bridge across Fountain Creek, and eight miles east on Hanover Road, which is primarily paved. The site is adjacent to and within sight of Hanover Road, which is not heavily used. An access road of less than one mile would be necessary to reach the site from Hanover Road. The bridge over Fountain Creek is limited to vehicles 11.5 feet high. An alternative route would be I-25 to the Fountain exit, through Fountain to Old Pueblo Road, and six miles south to Hanover Road.

3.3.4.1.2 Topographic Setting

The Wigwam site is located along and between two gentle ridges and near the head of a drainage. The area generally consists of gently rolling hills formed by differential erosion. To the west of the site, a large ridge several miles wide is supported by eolian sands above the Pierre Shale. Where the Pierre Shale is exposed at the surface, as on the site, gullying frequently occurs along drainages. In the site area, the gullying has been partially controlled by runoff diversion ditches.

3.3.4.1.3 Land Use and Ownership

Land use for the Wigwam site and surrounding areas is for cattle grazing. The nearest farmland is about two miles to the east, in SE 1/4 section 12 of the same township. The site is owned by the State of Colorado, as are adjacent lands. State and private lands in the vicinity of the site are shown in Figure 11.

The nearest house is about 1.5 miles to the northwest at the Hammer Ranch, located in section 13, T16S, R64W. To the southeast a house in section 13, T17S, R64W is over two miles away, as is a house to the east northeast in section 12, T17S, R64W.

3.3.4.2 Technical Evaluation

3.3.4.2.1 Geology

The Wigwam site is underlain by the Pierre Shale, which is about 2000 feet thick according to Scott and others (1978). A site investigation showed the surface to consist of silty topsoil with abundant fragments of siderite, with minor agate (possibly derived from the Slocum Alluvium). The siderite fragments are derived from concretions and thin beds of siderite within the Pierre Shale. The small hills in the northwest part of section 10 are supported by remnants of a thin siderite layer. Surficial material which has been mapped by Scott and others (1978) in the vicinity of the site includes eolian sand, the Piney Creek Alluvium and the Slocum Alluvium. Fine to coarse windblown sand is mapped west of the site along a large north-south trending hill. The Piney Creek Alluvium, located east of the site along Chico Creek, consists of silty to gravelly alluvium which is mapped as Qp (Figure 10). The Slocum Alluvium, weathered gravel mapped as Qt, is located east of Chico Creek.

No faulting has been mapped in the area. The site is located on the west limb, near the axis of the Denver Basin. The Pueblo Anticline, six miles west, is the nearest mapped fold. Beds dip approximately three degrees to the southwest (Tweto and others, 1978).

Sheet and rill wash are the dominant erosional features on the site, although gullying is developing in several areas near the center of the site. Geologic constraints on the site are limited to areas with a moderate erosion potential (Figure 12).

Usable minerals do not occur in the vicinity of the Wigwam site. Potential gravel deposits may occur in areas underlain by the Slocum Alluvium. The nearest oil and gas activity is in the Florence-Canon City Field about 40 miles southwest. The southernmost production in the Denver Basin is about 50 miles to the north.

3.3.4.2.2 Hydrology

All creeks in the area are intermittent washes with sandy or silty beds. Chico Creek, 1.5 miles downstream from the Wigwam site, has a dry sand bed 50 to 100 feet wide. Chico Creek flows into the Arkansas River approximately 25 miles south southeast of the site. It is mapped as intermittent throughout its course. Several stock ponds are in the vicinity of the site.

Ground water should not be affected significantly below or adjacent to the site, due to the low permeability of the Pierre Shale. The closest underlying aquifer is the Dakota Sandstone at a depth of about 2000 feet (Scott and others, 1978).

Few water wells are located in the vicinity of the site. Seven shallow wells drilled in alluvial aquifers are located adjacent to the candidate area in the same township. The nearest well is located about two miles to the east in section 12 and three wells are in section 13.

3.4 Southern Foothills Candidate Area

3.4.1 Previous Investigation

Little work has been performed on the geology of the Pierre Shale in the Southern Foothills Candidate Area. Most geologic work in the region has focused on the coal resources of the Raton Basin and on younger formations. Relevant references used in this section are Powell (1952), Harbour and Dixon (1956 and 1959) and Johnson (1958).

3.4.2 General Description

3.4.2.1 Location

The candidate area consists of a long, narrow band of Pierre Shale which is exposed at or near the surface just east of the foothills in Huerfano and Las Animas Counties in southern Colorado (Figure 13). It is about 70 miles long and averages about 10 miles in width. I-25 is located along the western side of most of the candidate area. About 95 percent of this area of exposed Pierre Shale is within 20 miles of I-25 and within the candidate area. The primary towns within the area are Trinidad and Walsenburg, near the southern and northern ends, respectively. Aguilar is located near the center of the area's western edge. Several major railroads transect the candidate area. The Denver and Rio Grande Western runs east-west through Walsenburg, the Colorado and Southern Railroad services Walsenburg and Trinidad, and the Atchison, Topeka and Santa Fe main line passes through Trinidad to Raton, New Mexico.

3.4.2.2 Topographic Setting

The Southern Foothills Candidate Area is in the western part of the Great Plains Physiographic Province, and is adjacent to the Rocky Mountain Province to the west.

Within the candidate area the topography consists of generally rolling hills, with occasional hogbacks or buttes formed by igneous intrusions. Elevations range from about 5800 to 6500 feet, with relatively low relief typical of the area.

Two conical mountains, East Spanish Peak with an elevation of 12,669 feet, and West Spanish Peak at 13,610 feet, rise abruptly west of the candidate area, and dominate the surrounding country. The land slopes from the peaks to the north, south, and east in a series of discontinuous steplike platforms. Igneous dikes crisscross the region, and where exposed by erosion stand as vertical walls up to 100 feet high. The area just west of the candidate area is characterized by steep escarpments ranging from 500 to more than 2,000 feet high above the surrounding plains.

3.4.2.3 Land Use and Ownership

The primary land use within the Southern Foothills Candidate Area is stock grazing. Most of the land within the candidate area is privately owned. Sections 16 and 36 in each township are typically state-owned. Only portions of these sections or other sections are state-owned in some cases.

3.4.2.4 Potential Sites

Three potential sites are located within the Southern Foothills Candidate Area (Figure 13). These are Rugby, the representative site, and the Del Aqua and Barela sites.

Fourteen other sites in the area were considered to have suitable formation and slope characteristics but are not recommended for other reasons. The reasons for eliminating these areas from further consideration were: location within 5 miles from a town (7 sites), insufficient size (5 sites), significant erosion potential, Quaternary igneous activity, proximity to critical surface water resources and location within sight distance of I-25 (3 sites each), and proximity to river flooding (1 site).

3.4.3 Technical Evaluation

3.4.3.1 Geology

The Southern Foothills Candidate Area is underlain by as much as 2000 feet of Pierre Shale, based on information in Johnson (1958). The candidate area boundary is delineated by the extent of surface or near-surface exposure of the Pierre Shale in the region. Shale thicknesses generally increase from west to east, and dips range from about one degree to ten degrees to the west, into the Raton Basin.

The flanks of the Raton Basin are characterized by uniform dips and relatively simple structure, however, several faults and folds complicate the structural geology of the region. A narrow northeasterly trending monocline is located three miles northwest of Aguilar, Colorado. The beds on the northeast side of the monocline are downfolded through a zone less than one quarter mile wide and have dips that may be as great as 50 degrees in places.

Geologic formations in the Southern Foothill Candidate Area differ from those present in the Central Plains or Central Foothills Candidate Areas.

The Purgatoire Formation of Early Cretaceous age rests unconformably on the Jurassic Morrison Formation, and is present in most of the Raton Basin. The Purgatoire Formation consists of a lower conglomeratic sandstone member, and an upper member composed of gray carbonaceous to coaly shale and interbedded thin sandstone. The Dakota Group lies conformably on the Purgatoire Formation. The Dakota Group, Benton Formation and Niobrara Formation are described in Section 3.1.2.4.

The Pierre Shale locally intertongues with the overlying Trinidad Sandstone through a transition zone 20 to 50 feet thick (Johnson and Wood, 1956). The Trinidad Sandstone ranges from about 140 feet to 300 feet thick. The upper Trinidad is a buff to light gray, medium-to-fine grained sandstone and the lower Trinidad is a buff to gray, very fine to fine-grained sandstone. Outcrops of the Trinidad Sandstone characteristically occur as one or two steep ledges or as a single massive cliff which separates the plateaus from the plains along the western side of the candidate area.

The Trinidad Sandstone is overlain by other Upper Cretaceous formations. These other Upper Cretaceous formations of the Raton Basin are not discussed in this report because they do not occur in the candidate area.

In late Eocene or early Oligocene time, extensive major faulting and folding occurred throughout the present mountainous areas of southeastern Colorado and northeastern New Mexico, in the area of the present day Sangre de Cristo and Wet Mountains. During this period, sedimentary rocks of the Raton Basin were intruded by numerous sills, dikes, plugs, stocks and laccoliths of basic to silicic composition. Volcanic stocks, which form the present-day Spanish Peaks, and related dikes were emplaced during this time. These intrusions had an intense metamorphic effect that was limited to relatively minor contact zones immediately adjacent to the intrusives.

Most of the dikes in the region are vertical or near-vertical and range in thickness from a few inches to more than 100 feet. Most of the dikes belong to two systems. The first system radiates from the Spanish Peaks area, and, along with some of the sills and small plugs, appears to be related to intrusive bodies that form the Spanish Peaks. The second, more extensive system, consists of subparallel dikes that are present throughout the entire region. The bearing of dikes in this system is northeasterly in the northern part of the Raton Basin region and nearly east-west in the southern part of the candidate area. The dikes, trending perpendicular to the axis of Raton Basin, were probably intruded along fractures resulting from tension during the folding of the basin. Other small localized swarms of dikes are present throughout the region (Johnson, 1958, 1961).

During Quaternary time, volcanoes near the southern parts of the candidate area extruded basaltic lava over large areas of the basin. Remnants of these flows are preserved on high mesas south of Trinidad. Sills were also intruded extensively into the sedimentary formations.

Quaternary alluvial deposits are found throughout the Raton Basin. Gravel and sand deposits, up to 30 feet in thickness, are present along many of the major present-day stream channels such as the Purgatoire and Vermejo Rivers. Landslide debris and talus cover many of the mountain slopes, and alluvial fans are found along the base of many mountains. Soil and pediment deposits cover much of the basin. Quaternary deposits generally are poorly sorted and unconsolidated.

No significant mineral deposits occur within the Southern Foothills Candidate Area. No oil and gas fields exist in the vicinity. Coal production from nearby parts of the Raton Basin has been significant, but the coal-bearing Vermejo Formation outcrops west of the candidate area. Sand and gravel deposits of economic significance may exist in local parts of the area.

3.4.3.2 Hydrology

The Southern Foothills Candidate Area forms the southwestern part of the Arkansas River Basin. The candidate area is drained by several northeasterly flowing streams and rivers and has a dentritic drainage pattern. The primary drainages are the Huerfano River, the Cucharas River, the Apishapa River and the Purgatoire River.
Evapotranspiration potential in the region is very high and many streams are intermittent in nature and flow only as a response to precipitation events.

The city of Trinidad collects and stores surface runoff as a municipal water supply. Most of the smaller communities either divert and store surface runoff, or dig large rectangular wells in the alluvium and pediment gravels that occur as a thin veneer within the region.

Numerous small lakes and reservoirs, all less than one square mile and most less than one quarter square mile, dot the area. No major reservoirs are present in the subject area.

Little is known about the water resources of the deeper formations in the region. This is due primarily to the low level of industrialization. Most of the water wells in the region are producing from shallow alluvial gravels less than 50 feet thick. In a few places, cisterns are used to store rain water.

Potential deep aquifers include:
1) Pre-Dakota rocks, including the Dockum group, the Ocate Sandstone, and the Morrison Formation, are probably of minimal economic value because they are generally located at great depths beneath the candidate area. The Ocate Sandstone has good permeability, as do the poorly cemented sandstone beds of the Morrison Formation, and probably would be of significant hydrologic value if located at shallower depths. The recharge area for these formations is west of the candidate area in the Vermejo Park Anticline.

2) The Dakota Sandstone probably is saturated with water confined under artesian pressure by the overlying Graneros Shale. The recharge area for this aquifer is probably west of the candidate area. Several seeps and wells are located southeast of the candidate area where well measurement indicates water movement to the southeast and south. Transmissibility is low because of the tightly cemented character of the sandstone. A study of the outcrops of the lower part of the aquifer suggests that it is somewhat more permeable than the upper part. Quality of the water from this aquifer is usually poor. Locally, at depth, it tends to be high in sodium chloride, sodium bicarbonate, and fluoride. Griggs (1948) postulated that its poor quality is caused by mixing of the Dakota Sandstone meteoric waters with gaseous and liquid igneous emanations related to the Quaternary igneous intrusives. The intrusives act like dams, and tend to slow movement of water through the Dakota Sandstone. Small to moderate yields, generally less than 10 gpm, are common for wells producing from the Dakota Sandstone. Large diameter wells have been known to produce up to 200 gpm (McLaughlin, 1956).

3) The Graneros Shale, a nearly impermeable formation, has specific capacities that are generally about 0.01 gpm/ft east of the region. Water quality is poor and generally suitable only for livestock.

4) The Greenhorn Limestone depends on connected fractures and solution channels for its permeability. Production of water would vary depending on the amount of fracturing, but in most cases, would likely to be at a low rate. Water quality of most wells producing

from the Greenhorn is fair, and it tends to be hard. Very small quantities of water can be expected from wells producing from this formation.

5) The Carlile Shale is impermeable except for the silty and limy portion immediately below the Fort Hays Limestone Member. Water from this formation generally is of good quality except for an odor of hydrogen sulfide.

6) The Fort Hays Limestone Member of the Niobrara Formation has a low permeability, but probably would sustain low-yield wells. Fractures are abundant at outcrops of the unit, but there is no evidence of solution channels.

7) The Smokey Hill Member is known to have low permeability. Several dry holes have been drilled into this formation. Some livestock wells producing 2 gpm are located east of the candidate area. Water from this formation generally is poor with a high concentration of magnesium and sodium sulfates.

8) The Pierre Shale generally is saturated within a relatively short distance of the outcrops. The shale is highly impermeable and yields virtually no water. In places, weathered shale found immediately below the land surface may transmit water. Water quality is poor and generally unsuitable for human consumption. Some of the water has the odor of hydrogen sulfide, and most of it has sulfate that can be tasted (Griggs, 1948) and a high concentration of dissolved solids. The water may be suitable for stock use in some areas, although large diameter wells are required to supply suitable quantities (Powell, 1952).

9) Quaternary alluvium, pediment and terrace deposits, generally less than 100 feet thick, represent a good potential source of fresh water. These surficial sediments consist of silt, sand, gravel, and boulders, and are recharged by infiltration of precipitation and influent stream conditions. The pediments occur as caps on the mesas southeast of Trinidad and near the Vermejo Park Anticline. The recharge water collects in a thin zone at the base of the gravel, moves downdip, and is discharged as seeps and springs. Wells producing from the pediment deposits generally yield low to moderate quantities of water, usually of good quality. The alluvial deposits are found in essentially continuous bands along streams and rivers of the region. The permeability of these deposits is variable, but generally is very high. In both the pediment and terrace gravels, the zone of saturation is found at the base of the deposit, and normally is less than ten feet thick. Water quality is variable but generally good. In isolated areas, the water can have excessive amounts of particulate matter or sulfates, depending mainly on the parent material of the alluvium. Alluvial deposits constitute the principal source of domestic water supplies in the Raton Mesa region.

10) Igneous rocks in the region include intrusive sill complexes and volcanic basalt flows, and are not thought to contain significant amounts of water. The intrusives are dependent on a poorly developed fracture system for the movement of water through the rock. However,

if of sufficient lateral extent, dikes may impound ground water moving through the formations they intrude. This situation has been observed in some parts of Colfax County in New Mexico (Griggs, 1948). Movement of ground water through volcanic complexes is less difficult, and results in thin water-bearing zones. Vertical water movement follows joints and fractures while horizontal movement follows both the fractures and interflow zones. Recharge from precipitation collects in these thin interflow zones, but there is a continuous loss to unsaturated zones below. Water in the lava eventually emerges from the downdip end of the flows through seeps and springs. Wells and springs, although not a principal source of water, yield small to large quantities of fresh water. Flows up to 80 gpm have been recorded from springs issuing from a basalt flow. Wells generally yield less than 10 gpm.

3.4.4 Representative Site Description - Rugby Site

3.4.4.1 General Site Description

3.4.4.1.1 Location

The Rugby site is located in section 36, T29S, R65W, in northwestern Las Animas County, approximately 5.5 miles northeast of Aguilar (Figure 14). It is approximately 14 miles southeast of Walsenburg, 23 miles north of Trinidad and 2 miles east of I-25. Access to the Rugby site is via I-25 to an exit 1.5 miles northeast of Aguilar, north 3 miles on an improved gravel road, and east 0.5 miles on a dirt road.

3.4.4.1.2 Topographic Setting

The Rugby site is situated on a generally east and northeast sloping surface having slopes generally less than ten percent and averaging two percent over most of the section. Slopes are steepest in the west-central portion, particularly where a terrace deposit is located (Figure 14). A minor ridge curves through the southern part of the section in a general east-west direction, and forms a divide between surface drainage to Salado Creek to the north and the Apishapa River to the south. The northern part of the site is at the head of drainage, and the remainder is near the head of drainage.

3.4.4.1.3 Land Use and Ownership

The land use for the site and surrounding area consists of open range grazing.

The Rugby site is owned by the State of Colorado. Peripheral private ownership is shown in Figure 15.

3.4.4.2 Technical Evaluation

3.4.4.2.1 Geology

Bedrock beneath the Rugby site is the Pierre Shale, which is approximately 2000 feet thick. Sandstone beds associated with the upper transition zone to the Trinidad sandstone crop out north and east of the site but were not observed on the tract. The underlying Niobrara is exposed along the banks of Salado Creek approximately one mile northeast of the site.

The closest observed intrusive dike is roughly 1.5 miles to the north, well out of the zone of influence.

Surficial materials on the site consist of weathered Pierre Shale everywhere except on one small knoll along the western section line. Here a small terrace remnant caps the underlying shale.

Major geologic constraints are absent in the site area (Figure 16); however, a moderate erosion potential is present in drainages adjacent to the site.

3.4.4.2.2 Hydrology

Surface hydrology is characterized by a total absence of defined drainage. All surface flow is sheet runoff to the north or south, as controlled by the low ridge that traverses the site.

Drainage for approximately the northern two-thirds of the site, north of the drainage divide, is to the northeast toward Salado Creek. This creek is an eastward flowing intermittent drainage about 0.2 miles north of the site. South of the drainage divide the flow is generally south and southeastward toward the Apishapa River.

Ground water in the area can be divided into two discrete units; shallow water in localized, unconfined, surficial deposits and deep water in regional, confined aquifers.

The shallow water is usually of relatively poor quality and wells produce at rates of 5 to 15 gpm. The principal use of this water is for stock watering with some limited domestic use. The nearest recorded wells to the site are one to two miles away.

The first important deep water production in the region is 15 gpm from a depth of 900 to 1000 feet, presumably from the underlying Fort Hays Limestone Member. This well is about 0.5 miles southeast of the southeast corner of the section. The other deep well in the site area is 2 to 3 miles to the southwest and is 2500 feet deep with a static water level of about 1100 feet. No production rate was recorded for this well.

4.0 Western Colorado - Potential Disposal Areas

4.1 Overview of Potential Disposal Areas

Three candidate areas, the Grand Valley, Lower Gunnison and Grand Hogback Candidate Areas, are located in western Colorado. Other suitable disposal areas may be present in western Colorado, but their remoteness from the major transportation network precluded their consideration in this report. Previous investigations identified other potential disposal sites in several specific areas. These areas include sites near Maybell (Moffat County), Uravan (Montrose County) and Disappointment Valley (San Miguel County). Additionally, a siting investigation by the Colorado Geological Survey identified several sites in Montezuma and La Plata Counties. These sites are not described in this report because of their distance from interstate highways.

The three candidate areas, located in the Mancos Shale and Wasatch Formation, are described in this section of the report. Specifically, the Grand Valley Candidate Area is discussed in Section 4.2 (Figure 17); the Lower Gunnison Candidate Area is presented in Section 4.3 (Figure 21); and the Grand Hogback Candidate Area is described in Section 4.4 (Figure 26). Each of these areas contain several potentially suitable sites, however, a single representative site description is included for each candidate area. Representative sites described herein are the Two Road, Cheney Reservoir and Estes Gulch sites.

4.1.1 Previous Investigations

Material for this section was derived from three basic sources: Colorado Geological Survey (1982) and U. S. Department of Energy (DOE) (1983, 1986a). These sources, part of the Uranium Mill Tailings Remedial Action Program (UMTRAP), are referenced only in instances where specific studies are described. Other sources are referenced wherever used.

4.1.2 General Area Description

4.1.2.1 Location

Potential disposal areas in western Colorado are within the general Grand Junction-Rifle area along the I-70/U.S. Hwy. 6 corridor (Figure 1). This area is specifically defined by a forty-mile wide corridor along I-70 from the Grand Hogback (east of Rifle) to the Utah state line. The Denver and Rio Grande Western Railroad closely follows this highway route. The Grand Junction-Rifle area is subdivided into three separate candidate areas. These areas are designated the Grand Valley, Lower Gunnison, and Grand Hogback Candidate Areas (Figure 1). The Grand Valley Candidate Area is located in an area approximately 15 miles by 40 miles extending northwest from Grand Junction to the Utah border. South and east of Grand Junction is the Lower Gunnison Candidate Area, within an area of about 10 miles by 15 miles. The Grand Hogback Candidate Area is located in several discrete areas north and south of a 60 mile stretch of I-70 between Glenwood Springs and Grand Junction.

4.1.2.2 Topographic Setting

The Grand Junction-Rifle area is entirely within the Colorado Plateau Physiographic Province. This province is characterized by deeply incised river channels flowing through sedimentary rocks, exposing large cliffs and relatively flat mesas. In the Grand Junction-Rifle area, the province is divided into two parts; the Canyonlands section to the south, and the Uinta Basin section to the north (Lohman, 1965). These two sections are separated from one another by the Book Cliffs, a prominent topographic escarpment formed by sandstones of the Mesaverde Group. The Canyonlands section in this area is characterized by monoclinal folds, plateaus and mesas. The Uinta Basin section north of Grand Junction and Rifle exhibits a mature stream-eroded upland surface known as the Roan Plateau. Principal physiographic elements within the study area include the Colorado River Valley, Gunnison River Valley, Uncompahgre Plateau, Grand Mesa, Battlement Mesa, and Roan Plateau.

The Colorado River Valley is subdivided into three distinct topographic areas. The relatively narrow DeBeque Canyon portion of the Colorado River Valley separates the broad open Grand Valley to the west from the steeply walled, but flat bottomed valley that lies to the east between the Roan Plateau and Battlement Mesa. Grand Valley is bounded by the Book Cliffs to the north and northeast, by the Uncompahgre Plateau to the south and southwest, and by Grand Mesa to the east. The valley averages about 12 miles wide and is characterized by several levels of long, deeply dissected pediments, or old channel deposits which sweep down from the base of the Book Cliffs towards the Colorado River (Sinnock, 1981a). This area, designated the Grand Valley Candidate Area, contains numerous potential disposal sites, including Two Road, McDonald Creek, 6 & 50 Reservoir, Camp Gulch, and East Salt Creek sites (Figure 17).

South of Grand Valley is the lower part of the Gunnison River Valley. The eastern part of this area contains multi-level gravel-capped pediments which slope towards the Gunnison River (Sinnock, 1981a). This area, termed the Lower Gunnison Candidate Area, contains at least two potential sites (Figure 21).

East of De Beque Canyon is the Grand Hogback Candidate Area. This area has a complex topography that includes mesas, canyons, and river valleys. Four potential sites, Flatiron Mesa, Lucas Mesa, Pyramid Rock and Estes Gulch, are located in this candidate area (Figure 26).

The entire Grand Junction-Rifle area is drained by the Colorado River and its tributaries, including the Gunnison River (Schwochow, 1978). The principal tributaries of the Gunnison River, which include Indian Creek, Kannah Creek, and Whitewater Creek, are perennial streams. In contrast, most creeks in the Grand Valley area are ephemeral. Exceptions to this general rule are West Salt Creek and East Salt Creek, which generally flow all year.

4.1.2.3 Land Use

Candidate areas in western Colorado contain both public and private lands. Public lands are administered by the U.S. Bureau of Land Management (BLM), which maintains a district office in Grand Junction and area offices in Grand Junction and Glenwood Springs.

The primary use for public lands in the Grand Junction-Rifle area is cattle grazing and wildlife habitat. Present uses of these lands, however, may be modified in the near future as a result of development pressures. BLM lands can be assumed to be subject to grazing permits, and some sites or adjacent lands could be traded or sold for development.

The entire Grand Junction-Rifle-Glenwood Springs corridor has recently undergone an explosion of population and growth related to energy development, followed by an economic depression when development plans changed drastically. Oil shale development may be a major factor in the long range development of this area, particularly for the DeBeque-Parachute-Rifle area. Coal development and generation of electricity from coal-fired power plants may also cause significant changes in the present use patterns of not only the private lands but also of adjoining public lands.

A proposal presently under study by the U.S. Bureau of Reclamation to divert saline waters from the Glenwood and Dotsero Springs areas may result in the utilization of several thousand acres in the Mack area for brine evaporation and salt disposal purposes. Two of the potential disposal sites (Two Road and McDonald Creek) coincide with areas that are being considered for this salinity control project.

A proposal by the U.S. Bureau of Reclamation to construct the Dominguez Dam, about one mile upstream from the town of Whitewater on the Gunnison River, is presently in the study and evaluation stage. The highwater elevation for the reservoir would be 4800 feet for a plan based on an 18-megawatt generation plant, or 4860 feet for a plan based on a 36-megawatt plant. Domestic usage of Gunnison River waters would probably be vastly increased by such a project.

Oil and gas leases are present in the area, which may be subject to development of potential oil and gas resources. The primary resource target is natural gas within the Dakota, Wasatch, Mesaverde, Morrison, and Entrada formations. All candidate areas have some potential for future gas and/or oil production. Although the use of a specific area for disposal purposes is not necessarily incompatible with exploration and development of its oil and gas resources, the existing rights of the lessees and potential mitigation measures should be fully considered in any future siting efforts.

The potential for development of the candidate areas for other mineral resources is possible, but is remote for specific sites. The gravels and shales that comprise the surface of all of the sites are not sufficiently unique to be considered a highly valuable resource. All potential sites are underlain by coal, but the beds are to deep and/or too thin to be considered economic.

Energy-related developments may result in the encroachment of housing areas toward presently remote sites. Other current uses of the proposed sites include recreation activities such as hunting and off-road vehicle driving. Such uses will undoubtedly increase in proportion to population growth.

4.1.2.4 Geology

Stratigraphy: Rock layers in the Grand Junction-Rifle area are inclined to the north and northeast. The oldest rocks are exposed to the southwest and become progressively younger to the northeast. The oldest rocks exposed in the area are the complexly folded Precambrian schists and gneisses found in the Uncompahgre Plateau (Lohman, 1981). The oldest of the sedimentary formations, the Triassic Chinle Formation, unconformably overlies these Precambrian rocks. The large time interval missing between the Precambrian and Triassic rocks supports the premise that the Uncompahgre Plateau was uplifted and eroded some 220 to 250 million years ago, then subsequently buried by a thick sequence of sedimentary rocks. The lower part of this sequence in the Grand Junction area has a thickness of over 500 feet and includes the Triassic Chinle Formation, Wingate Sandstone, and Kayenta Formation (Figure 3).

Overlying these layers are approximately 800 feet of Jurassic rocks, including the Entrada Sandstone, Summerville Formation, and Morrison Formation. Of primary interest in this report are the overlying Cretaceous formations, in particular the Mancos Shale, the only "suitable formation" in this region for the disposal of low-level radioactive materials. Of the approximately 7,000 feet of Cretaceous rocks present in the Grand Junction-Rifle area, the Mancos Shale comprises about 4,000 feet. It is wedged between the underlying Dakota Sandstone and the overlying Mesaverde Group. A number of formations comprise the Mesaverde Group, but the two most prominent are the Hunter Canyon and Mount Garfield Formations.

The "potentially suitable formation" in this region is the Wasatch Formation, an interbedded sequence of shale, siltstone, and sandstone of early Tertiary age which overlies the Mesaverde Group. The Wasatch Formation is divided into three members by Donnell (1961). Shale and claystone dominate the lower and upper members, whereas the middle member is primarily sandstone. The three potential sites are in the upper member of the Wasatch Formation. Overlying the Wasatch Formation is the Tertiary Green River Formation, which is comprised of rich oil shale (Lohman, 1981). This formation forms much of the impressive Roan Cliffs, exposed along the Colorado River near Rifle.

Surficial Deposits: Surficial deposits in the region range from Late Pliocene to Holocene in age. Glacial tills, probably of Bull Lake and Pinedale age (Late Pleistocene), cover the surface of Grand Mesa (Yeend, 1969). These are composed of unsorted material ranging from clay to boulders, deposited by at least four episodes of Pleistocene glaciation. The thickness of these materials ranges from 5 to 75 feet. Extensive landslide deposits of Pleistocene and Holocene age occur on the flanks of Grand and Battlement mesas and in the area west of DeBeque. These deposits are the result of slumping, rock and debris falls, rockslides, and solifluction movements. These movements occurred throughout the Pleistocene and are continuing today.

Surficial deposits, including pediment, terrace, flood plain, and residual deposits of Late Pliocene to Pleistocene age occur in the study area. Pediment deposits are thin, discontinuous deposits of clayey silts, sand, and gravel, resulting from local flooding and slopewash. They range in age from Pleistocene to Holocene and are most common in areas underlain by Mancos Shale. These deposits are frequently mantled by a thin (three to six foot) cover of eolian silt and fine sand which may be strongly cemented by caliche. Caliche crusts on gravel and boulders are common. Terraces occur at various elevations above the Colorado and Gunnison Rivers and Plateau Creek and are underlain by gravels which range in age from Early to Late Pleistocene. The oldest gravels are 30 to 450 feet above modern stream levels, and may be of pre-Bull Lake age. Younger terraces correlated with Pinedale and Bull Lake glaciations (Yeend, 1969; Whitney, 1981; Sinnock, 1981) generally occur between 15 and 70 feet above the modern channels.

The modern floodplains are underlain by unconsolidated clay, silt, sand, and gravel deposits, that are in excess of 20 feet thick along the Colorado River. Residual deposits, developed from Late Pleistocene to Holocene weathering of the Mancos Shale, floor much of the Grand Valley.

Geomorphology: A number of geologists have investigated the development of drainage patterns, terraces, sediments, and glacial moraines in the Grand Valley region. The following discussion is derived from articles by Hunt (1956), Lohman (1965, 1981), Yeend (1969), and Sinnock (1981a,b).

The Grand Junction area and adjacent parts of the Colorado Plateau were undergoing erosion by the ancestral Colorado River system until the beginning of the Pliocene. The course of the Colorado River, probably established by the end of the Miocene, was changed by differential uplift of the Uncompahgre Arch during the Pliocene. This caused major changes in the drainage patterns of the Colorado and Gunnison Rivers. Lohman (1965, 1981) presents evidence that the ancestral Colorado and Gunnison Rivers once flowed through Unaweep Canyon and that the present pattern evolved from successive stages of stream piracy by tributary streams cutting Mancos Shale north and west of the Uncompahgre Arch. The more rapid rate of stream downcutting in the Mancos than in the Precambrian granitic terrain of the Uncompahgre Uplift was the determining factor. Sinnock (1981b), on the other hand, believes that Unaweep Canyon was formerly occupied by the Gunnison alone, and that the Colorado River has been in essentially the same position relative to the Uncompahgre Uplift since the Miocene. The diversion of the Gunnison away from Unaweep Canyon is attributed to successive stages of uplift of the Uncompahgre Arch.

Structure: Regional structure in the Grand Junction-Rifle area consists of broad uplifts and deep structural basins (Schwochow, 1978). The Uncompahgre Uplift, which trends northwest-southeast, is the most obvious structural feature. Evidence indicates that the Uncompahgre Arch was uplifted as recently as three million years ago (late Pliocene or early Pleistocene) (Lohman, 1981). The Uncompaghre Uplift is bounded by the Paradox Basin to the southwest and by the Piceance Basin on the northeast.

These uplifts and basins have folds and faults associated with them. For example, the northeast margin of the Uncompahgre Uplift is bounded by normal faulting and monoclinal folding. Evidence for late Quaternary to Holocene movements on these faults is not conclusive but they may be active at this time. To the northeast and east of Rifle, the Grand Hogback Monocline marks the boundary between the Colorado Plateau and White River Uplift. In some areas this major folded structure has been locally faulted. In Grand Valley the Mancos Shale generally dips two to ten degrees to the north and northeast into the Piceance Basin, but many small folds and a few faults locally complicate the structure.

The Mancos Shale and Wasatch Formation near the surface may contain horizontal and vertical joints. These joints often contain gypsum and occasionally calcite (Lohman, 1965) and may provide sufficient porosity and permeability to allow the accumulation and movement of water. More information about jointing in these units can be found in the report by Lohman (1965).

Mineral Resources: An abundance of mineral resources occurs within the Grand Junction-Rifle area. The Piceance Basin contains oil, natural gas, coal, uranium, sand, gravel, and a high percentage of the world's oil shale. The principal petroleum-bearing formations include, in order of increasing age, the Wasatch Formation, Mesaverde Group, Dakota Sandstone Burro Canyon Formation, Morrison Formation, and Entrada Sandstone. Because some these formations underlie the entire study area, there is a possibility that oil or gas occurs beneath any potential site within the candidate areas.

Economically significant coal deposits are known to occur in only one formation in the area, the Mesaverde Group. The Mesaverde Group is found north and northeast of the Book Cliffs, and east of the western base of Grand Mesa. Four sites, the Lucas Mesa, Flatiron Mesa, Pyramid Rock and Estes Gulch sites, are underlain by the Mesaverde Group, and therefore may have coal in the deep subsurface beneath them. The Dakota Sandstone locally contains thin coal beds, but nowhere in the study area are there known Dakota coal beds of commercial interest. None of the candidate areas are underlain by important, shallow coal deposits.

Thick oil shale deposits occur in the Parachute Creek member of the Green River Formation. A significant part of the known oil shale reserves in the United States occurs in this formation in the Piceance Basin. None of the candidate areas are underlain by important oil shale deposits.

Uranium and vanadium deposits are known to occur in the Dakota Sandstone, Burro Canyon Formation, Morrison Formation, Entrada Sandstone, and Wingate Sandstone (Schwochow, 1978; Fischer, 1960). These formations occur throughout most of the study area; however, their extreme depth beneath the surface virtually eliminates the possibility of economic recovery of these potential resources in the candidate areas.

Sand, gravel, and aggregate resources are relatively abundant in the study area. Such resources occur in terraces and modern alluvium along the Colorado and Gunnison Rivers, and in pediment deposits along the Book Cliffs, Grand Mesa, and Battlement Mesas. In general the most sound sources of riprap are pediment deposits shed from Battlement and Grand Mesas. These deposits contain well-indurated clasts of basalt that have excellent engineering characteristics. Pediment gravels from the Book Cliffs, river terraces, and modern alluvium often contain an abundance of shale and sandstone clasts, and these types of clasts may not be suitable for construction or riprap purposes.

Seismicity: The Grand Junction-Rifle area is a region with moderate earthquake potential. Historically, the area has been relatively free of any damaging earthquakes, but several small to moderate non-damaging earthquakes (magnitude less than about 5.0) have occurred in the area. A number of faults are present in the area, but only a few are classified as "potentially active". Faults that bound the Uncompahgre Uplift, and a few minor faults along the Grand Hogback near Glenwood Springs are identified as potentially active (Kirkham and Rogers, 1981).

The Colorado Geological Survey (Kirkham and Rogers, 1981) places the study area in the Colorado Plateau seismotectonic province. Within this province earthquakes with a maximum magnitude of 5.5 to 6.5 may occur.

Because the repository design considered in this report will place radioactive wastes below ground, future ground shaking poses little threat to the long-term stability of the repository. Direct fault displacement or ground deformation associated with an earthquake, however, could theoretically disrupt the repository. Any potential site will need to be further evaluated for seismic hazards, in particular for ground rupture, during detailed site studies.

4.1.2.5 Hydrology

Surface Water: The Grand Junction-Rifle area is in the Colorado River Basin. The Colorado River has its headwaters high in the Rocky Mountains of central Colorado on the west side of the Continental Divide. Its drainage area upstream of Grand Junction is approximately 8900 square miles. The principal tributaries of the Colorado River in Colorado are the Roaring Fork, Gunnison, and Dolores Rivers. The Roaring Fork joins the Colorado upstream from all of the candidate areas; the Gunnison, which is the largest of these tributaries, joins the Colorado at Grand Junction; and the Dolores joins the Colorado downstream from the sites in Utah.

The Colorado River near DeBeque, between Rifle and Grand Junction, has an average minimum monthly flow of about 1580 cubic feet per second (cfs), and average maximum monthly flows of approximately 11,200 cfs. The 7-day 10-year low flow (average minimum

7-day flow occurring once in 10 years) is 1140 cfs. Downstream from the sites, at the Colorado-Utah border, the average minimum and maximum monthly flows are approximately 3140 and 16,700 cfs, respectively, and the 7-day 10-year low flow is 1230 cfs. These higher flows are attributable mainly to the Gunnison River.

In general, the quality of water in the Colorado River depends on the flow, and the flow is determined by the source of water. During low-flow periods, when surface runoff is low and the river flow is basically discharged ground water, the concentration of metals and inorganics leached from the soil is high. During high-flow periods, when the river flow is mainly surface runoff, the concentration of metals and inorganics is low and the concentration of organics and suspended solids is high.

There are no major domestic users of Colorado River water for 200 miles downstream from Grand Junction (Ford, Bacon & Davis Utah, 1977a). The normal water supplies for Grand Junction are obtained from Grand Mesa surface water, the Juniata and Perdy Mesa reservoirs being the major sources. During dry spells, Grand Junction can use Gunnison River water; the intake is approximately one mile upstream from the confluence with the Colorado River. The Ute Water District uses Colorado River water during dry spells.

Ground Water: Formations with significant amounts of ground water in the Grand Junction-Rifle area are described by Repplier and others, 1981; Wright Water Engineers, 1979; Boettcher, 1972; Coffin and others, 1968; Lohman, 1965. These formations include, in order of increasing age, the Green River Formation, Mesaverde Group, Dakota Sandstone, Burro Canyon Formation, Entrada Sandstone, and Wingate Sandstone. The middle part of the Wasatch Formation includes sandstones capable of producing relatively large quantities of water. The upper part (Shire member), however, is dominantly shale and claystone, and contains only minor amounts of water. The Mancos Shale generally produces only minor amounts of poor quality water. The availability of water within the Mancos Shale is usually related to fracture porosity and permeability.

The existing ground water environment for specific representative sites is discussed in subsequent sections of this report. Features which are considered include hydrostratigraphy, hydraulics, water quality, and water use. The existing environment at the representative sites was defined by means of field investigations which included test borings and monitoring wells. Hydraulic testing, periodic water-level measurements, and repetitive water-quality sampling were conducted at each site.

4.2 Grand Valley Candidate Area

4.2.1 Previous Investigation

Material for this section was derived extensively from three basic sources: Colorado Geological Survey (1982) and U. S. Department of Energy (DOE) (1983, 1986a). These sources, part of the Uranium Mill

Tailings Remedial Action Program (UMTRAP), are referenced only in instances where specific studies are described. Other sources are referenced wherever used.

4.2.2 General Description

4.2.2.1 Location

The Grand Valley Candidate Area is located in west-central Mesa County and extreme southwestern Garfield County. The candidate area extends from Grand Junction to the Utah border in an elongate band 10 to 15 miles wide where the Mancos Shale is at or near the surface (Figure 17). Five potential sites are located within the candidate area and are named Two Road, McDonald Creek, 6 & 50 Reservoir, Camp Gulch, and East Salt Creek.

4.2.2.2 Topographic Setting

The Grand Valley Candidate Area is in the lower portion of the Grand Valley north of the Colorado River. Eroded pediment surfaces and small intervening basins, which slope with low relief generally to the south toward the river, typify the area. The Book Cliffs and Uncompahgre Plateau are the primary physiographic elements bordering the candidate area. Elevations within the candidate area range from about 4500 to 5500 feet, while elevations of 7000 to 8000 feet are typical in the Book Cliffs to the north and northeast. The Uncompahgre Plateau has elevations of about 9000 to 10,000 feet. The Grand Valley extends to the west and southeast of the candidate area along the Colorado River.

4.2.2.3 Land Use and Ownership

Approximately 70 percent of the land within the Grand Valley Candidate Area, is owned by the Federal Government and administered by the U.S. Bureau of Land Management (BLM). These BLM lands are all subject to existing oil and gas leases. All five potential sites are located on BLM land, and grazing is the predominant land use for all sites. Special land uses must be thoroughly investigated for any site likely to be developed. Two special land uses are described below.

A possible salt evaporation pond site could affect two of the potential sites, Two Road and McDonald Creek. This proposed evaporation pond is connection with the Glenwood-Dotsero Springs unit of the Colorado River Water Quality Improvement Program, under consideration by the U.S. Bureau of Reclamation. Saline waters would be transported by ditch and/or pipeline from a collection point near Dotsero and Glenwood Springs to the evaporation pond site. Location of the salt evaporation pond may be altered during later detailed studies by the U.S. Bureau of Reclamation.

Colorado Ute Electric Association has applied to the BLM for the purchase of 3,000 acres of land north of Mack. This land is the possible site of a coal-fired electrical generation plant.

4.2.2.4 Potential Sites

Five potential sites are located within the Grand Valley Candidate Area (Figure 17). These are Two Road, the representative site, and the McDonald Creek, 6 & 50 Reservoir, Camp Gulch and East Salt Creek sites. Ten other sites in the area were considered to have suitable formation and slope characteristics but are not recommended for other reasons. The reasons for dropping these areas from further consideration were: severe erosion potential (8 sites), critical mineral resources, susceptibility to flash flooding, severe transportation hazards and insufficient size (3 sites each), and high relief, potentially irrigated land, future growth area and densely populated area (1 site each).

4.2.3 Technical Evaluation

4.2.3.1 Geology

The Grand Valley Candidate Area is underlain by about 0 to 3000 feet of Mancos Shale, based on structure contour mapping by Cashion (1973). The candidate area boundary is delineated by the extent of surface exposure of Mancos Shale in western Grand Valley. Shale thicknesses generally increase from south to north, and dips range from about five degrees to the southwest to ten degrees to the northeast.

There are few bedrock exposures of the Mancos Shale in the candidate area. A relatively thin veneer of surficial deposits, primarily terraces along the Colorado River and pediment and eolian deposits in upland areas, overlies the Mancos Shale in the area.

Structurally, the candidate area is on a homocline on the southern edge of the Piceance Basin just north of the Uncompahgre Uplift. A series of anticlinal folds is predominant in the western part of the area. These folds and associated lineaments are related to the the Uncompahgre uplift to the south. Potentially active faults associated with the Uncompahgre Uplift are all south of the candidate area.

All five potential sites are located in areas currently undergoing either sheet or rill wash where the erosion potential is moderate. Intervening areas along major gullies are subject to a higher erosion potential, especially where fine-grained, easily eroded deposits are at the surface.

There is some oil and gas development within the Grand Valley Candidate Area. Ten relatively small oil and gas fields are located in the area, all within the northern half of the candidate area (Scanlon, 1983). These are the Carbonera, South Canyon, Garmesa, Rock, Bar X, Highline Canal, Coyote Wash, Mack Creek, Fruita and Asbury Creek fields. No wells are located on any potential site, but some are within 0.5 miles of the sites. Some coal in the Dakota Sandstone underlies the candidate area. There is no evidence that it is economically significant, due to thinness and its depth of several hundred to about four thousand feet. Pediment gravels within the candidate area are not of any great commercial value because of their relatively poor sorting, their location relative to potential markets, and the availability of superior materials in the vicinity.

4.2.3.2 Hydrology

The predominant surface water features within the candidate area are the Colorado River and a series of canals paralleling the river, all of which flow generally northwest. Major creeks flowing primarily southward into the Colorado River include West Salt Creek, East Salt Creek, Big Salt Wash and Little Salt Wash. All four creeks are ephemeral in their upper reaches, above the Highline Canal, and transport only minor amounts of water seasonally. The flood potential for the area is low, except for these major drainages and along the Colorado River. Only three lakes are mapped at a scale of 1:250,000 for the candidate area. These are Highline Lake and Mack Reservoir, both about 5 miles north of Mack, and Ruby Lee Reservoir, about 12 miles north of Fruita.

The first underlying important aquifer is the Dakota Sandstone, at a depth ranging from 100 to 4000 feet beneath the ground surface. Water within this formation is probably saline and may be contaminated by hydrocarbons. Localized perched water zones may occur at the bedrock/surficial materials contact or in fractured zones in the Mancos Shale.

Very few water wells are located in the candidate area, since useable groundwater occurs at great depths. Five wells are located in T1W, R1N just northwest of Grand Junction. Three of these are deep, ranging from 700 to 1800 feet. Only two wells, both less than 100 feet deep, are within the remainder of the area. These are located in section 36, T7S, R102W, and section 16, T7S, R103W.

4.2.4 Representative Site Description - Two Road Site

4.2.4.1 General Site Description

4.2.4.1.1 Location

The Two Road site is in Grand Valley about 28 miles (33 road miles) northwest of Grand Junction in Mesa County (Figure 17). It is two miles east of the Utah-Colorado border and is about five miles north of I-70. This site is a north-south elongate area almost 3 miles long by 0.5 miles wide located in sections 7, 8, 17, 18, 19, and 30 of T9S, R104W (Figure 18). The area is bisected by a northwest-southeast trending dirt road called Two Road, and is 3.4 miles northwest of the intersection of Two Road and U.S. Hwy. 6 & 50. The town of Mack is approximately ten miles east of the site.

4.2.4.1.2 Topographic Setting

The Two Road site is situated on a gently south-sloping, elongate pediment surface (Figure 18). East of the pediment surface lies a broad shallow drainage basin with slopes generally less than five percent. West of the Two Road site is an ephemeral stream which has dissected the underlying sediments to form slopes steeper than five percent and in places greater than ten percent. Total relief in the site area is less than 150 feet over a three mile distance, ranging from about 4830 to 4960 feet in elevation.

4.2.4.1.3 Land Use and Ownership

The Two Road site is located on remote public lands administered by the U.S. Bureau of Land Management (Figure 19). The site is within a BLM grazing allotment. The grazing of sheep on the area's sparsely vegetated rangeland is the primary use of the land. Deer are the dominant wild grazing animals, however, their numbers are few in the vicinity of the site. The site is also under oil and gas leases, and an underground natural gas pipeline, running northwest-southeast, is located approximately one mile northeast of the site (Logan-Pearce, 1985).

The nearest residence to the site is a mobile home just east of the intersection of Two Road and U.S. Highway 6 & 50. The location supports a sheep operation, including lambing pens and a small reservoir for watering. A pumping station is located approximately two miles to the southeast of the site. An agricultural area, including residences, begins approximately five miles east of the site and extends east and south toward Mack. Privately owned land lies approximately three miles to the south.

4.2.4.2 Technical Evaluation

4.2.4.2.1 Geology

Approximately 500 to 1400 ft of Mancos Shale underlies the Two Road site, based on structure contour mapping by Cashion (1973) and nearby petroleum drill holes. Shale thickness increases from south to north, primarily as a result of structural tilting. The site lies almost directly on and slightly west of the axis of the Bar X Anticline. This is a regional structure which lies along the extension of the northeast flank of the Uncompahgre Uplift. Bedrock in the site area is thought to generally dip northward or northwestward at two degrees to five degrees. No bedrock exposures occur on site; therefore, it was necessary to calculate the dips from the structure contour map of Cashion (1973).

The site is on surficial deposits that rest on a pediment surface or channel deposit of unknown age, formed on the Mancos Shale. Two broad, relatively flat pediment deposits are dissected by several intermittent streams. The surface is 40 to 60 feet above adjacent ephermeral creeks and 50 to 80 feet above Bitter Creek, the primary drainage in the area. Shallow test pits and poor exposures along the periphery of the site suggest the unit is dominantly clayey, silty small pebble gravel that is an estimated three to six feet thick along the perimeter of the site. If the unit represents an old channel deposit, the gravels may be thicker in the middle part of the channel. The gravel clasts consist of reworked sedimentary rocks from the Book Cliffs and Roan Cliffs and are primarily sandstone, chert, and shale, with minor amounts of other types of sedimentary clasts. A thin veneer of red-brown wind blown silt commonly overlies the pediment gravel on parts of the site.

The surface configuration of the site area is that of an elongate, gently arched ridge. It is uncertain if the modern topographic surface coincides with the older depositional surface. The old surface may have been eroded on its edges and thus lowered by erosion. It is also remotely possible that the old pediment deposit has been structurally arched since deposition. This possibility needs further evaluation if Two Road site is recommended for future evaluation.

The dominant surficial materials present in the site area are residual soils formed by weathering of the Mancos, pediment gravels, and eolian deposits. The subsurface profile, based on logs of exploratory boreholes and test pits on the site (SHB, 1985a) consists of the following:

- Eolian deposits: This layer consists of clayey silt and fine sand and varies in thickness from about one foot to six feet.
- Pediment deposits: This layer generally consists of interlayered sand and gravelly sand, with occasional gravel lenses. This unit ranges from about 15 to 25 feet in thickness across the site, and may extend to depths of 30 feet or more. It is generally cemented by caliche.
- Mancos Shale: This unit is gray to olive or black with occasional thin beds of sandstone and limestone. The upper 10 to 20 feet is highly weathered, forming a residual soil in places. The zone of weathering appears to be between 20 and 60 feet in depth (URS, 1983).

Presently, minor sheet and rill wash occur on the site, however, the gravel cap has effectively prevented any severe erosion. The drainage systems on the site are characterized by very gentle, grassy slopes, and the lack of deeply incised channels, although incised gullies flank the site on the east and west. Because the site lies on a drainage divide, there is little potential for flash flooding. The major geologic constraint that affects the long-term stability of the site is areas of severe erosion potential along the ephemeral creeks adjacent to the site (Figure 20). In general, the site is geomorphically stable, with erosion limited by the gravel cap that protects the underlying Mancos Shale.

There are moderate potential conflicts involving mineral resource recovery for the Two Road site. As with most sedimentary basins, there is some potential for oil and gas beneath the site and several active oil and gas leases exist. Primary underlying potential reservoir rocks include the Dakota Sandstone, Morrison Formation, and Entrada Sandstone. Several tests wells have been drilled within a mile of the site, but all were plugged and abandoned (Figure 20). A small amount of gas was reported in the #1 Gov't Krey well in SE 1/4 NW 1/4 section 10, but the volume was far too little to make a gas well. The topographic base map indicates the well in the NW 1/4 section 18 is a gas well, but the records of the Colorado Oil and Gas Conservation Commission indicate the well was dry and plugged. The Dakota Sandstone contains thin coal beds in some areas, but it is highly unlikely that this would ever become an economically recoverable resource.

The lithologic and size characteristics of the gravel deposit that underlies Two Road site are not favorable for an economic source of sand or gravel. Likewise, it is improbable that the unit will contain any significant amount of useable riprap. The nearest potential sources of riprap include quarried sandstone from the Dakota Sandstone or Entrada Sandstone a few miles southeast of the site, quarried sandstone from the Mesaverde Formation exposed in the Book Cliffs several miles north, river gravel along the Colorado River several miles to the southeast, and basaltic pediment gravels from the west flank of Grand Mesa.

4.2.4.2.2 Hydrology

The Two Road site is located in the Colorado River Basin. There are no major streams, lakes, springs, or irrigation ditches within two miles of the Two Road site. Several creeks occur in the area, but according to U.S. Geological Survey topographic maps all are ephemeral. The site lies on a drainage divide between two unnamed ephemeral creeks. These creeks join Bitter Creek about 0.5 to 1 mile south of the site. McDonald Creek flows approximately 1.5 miles east of the site. West Salt Wash and Badger Wash join approximately six miles southeast of the representative site. The Colorado River is over five miles south of the site, at an elevation 500 feet below that of the Two Road site.

An area of only 35 acres drains toward the site. Elevations in the watershed range from 4945 feet to 4965 feet above sea level. Deeply incised gullies are not present at the Two Road site, but do occur to the east and west. Data on historical floods is not available for the Two Road site. Due to the distance from and elevation above perennial flowing waters, river flooding would not impact the Two Road site.

Water-quality monitoring gauging stations do not exist on any of the creeks or ephemeral streams in the Two Road site area. Data taken on West Salt Creek east of the site indicate that the major chemical constituents of the water are sodium, magnesium, calcium, and sulfate. During flow events total dissolved solids values were high, ranging from several hundred to over 10,000 mg/l. It is expected that the water quality during flow events would be similar in the drainages adjacent to the site (URS, 1983).

Surface water in the vicinity of the site is used for stock watering and for casual use by wildlife. Because of the low precipitation and high evapotranspiration in the area, the potential surface-water development in the area is probably small. Usage in the area would probably continue to be limited to stock watering and casual use by wildlife. The value of surface water resources in the vicinity of the Two Road site will likely remain low in the future.

The surficial materials on the Two Road site contain little or no water. It is possible that the surficial unit may temporarily hold small amounts of water following periods of heavy precipitation, but any such water would rapidly dissipate because of evaporation or seepage around the flanks of the site.

Examination of the Colorado Division of Water Resources' records indicated there are no registered water wells or decreed springs in the township that includes Two Road site. There are no existing water rights in the township immediately to the west of the site (T17S, R26E). There are two wells in T18S, R26E which is to the southwest of the site. One is a hand-dug well 11 feet deep in section 16, approximately four miles from the site. The other is the U.S. Bureau of Reclamation's Bitter Creek Well in section 30, approximately six miles from the site. No ground water was encountered during the 1985 field program (DOE, 1986a). Ground water occurs intermittently below a nearby stock pond which is approximately 1000 feet east of the the site (URS, 1983). There probably is ground water in the alluvium underlying washes on either side of the site. The water quality in these washes is poor based on reports for a well about four miles southwest of the site (State of Utah, 1938). There is no known use of ground water within four miles of the site. In general the Mancos Shale produces only minor amounts of poor quality water found in fractured zones (Lohman, 1965). The first underlying potential aquifer is the Dakota Formation, 500 to 1400 feet below the ground surface, but this aquifer is generally of poor quality and may be contaminated by hydrocarbons. Because of the limited amount and poor quality of shallow ground water, the potential use is minimal.

4.3 Lower Gunnison Candidate Area

4.3.1 Previous Investigation

Material for this section was derived extensively from three basic sources: Colorado Geological Survey (1982) and U. S. Department of Energy (DOE) (1983, 1986a). These sources, part of the Uranium Mill Tailings Remedial Action Program (UMTRAP), are referenced only in instances where specific studies are described. Other sources are referenced wherever used.

4.3.2 General Description

4.3.2.1 Location

The Lower Gunnison Candidate Area is located in south central Mesa County in the southeast part of Grand Valley (Figure 21). The candidate area is east of the Gunnison River between its confluence with the Colorado River and the Mesa-Delta County line. It covers an area of approximately 180 square miles where the Mancos Shale is exposed at or near the surface. A section of U.S. Hwy. 50 between Grand Junction and Delta traverses the western side of the candidate area.

4.3.2.2 Topographic Setting

The Lower Gunnison Candidate Area is located physiographically within the Gunnison River Valley. Surrounding physiographic elements of the Colorado Plateau province are Grand Mesa to the east, the Uncompahgre Plateau to the southwest, and the Colorado River Valley to the north. These physiographic elements are described in Section 4.1.2.2.

The western edge of Grand Mesa is a steep escarpment that grades to multi-level gravel-capped pediments which slope towards the Gunnison

River (Sinnock, 1981a). Potential sites are located on a low lying pediment surface (Cheney Reservoir site) and in an eroded basin between pediment surfaces (Halls Basin site).

Principal tributaries of the Gunnison River within the candidate area include Indian Creek, Kannah Creek and Whitewater Creek.

4.3.2.3 Land Use and Ownership

A large portion of the Lower Gunnison Candiate Area (approximately 60 percent) is within public lands administred by the U.S. Bureau of Land Management. These federal lands, outlined in Figure 21, are subject to existing oil and gas leases. The primary land use of the area is for grazing.

The northern part of the Lower Gunnison Candidate Area is in the vicinity of Grand Junction, and is subject to development pressures. Land use restrictions should be evaluated on a site-by-site basis.

4.3.2.4 Potential Sites

Two sites, Halls Basin and Cheney Reservoir are considered potential sites. Cheney Reservoir is designated as the representative site. Five other sites within the Lower Gunnison Candidate Area with favorable formation and slope characteristics were considered for waste disposal, but were not recommended for other reasons. The reasons for not further considering the other 5 sites are insufficient size (4 sites), severe erosion potential (3 sites), high relief (2 sites), and future growth area, severe transportation hazards or proximity to a public water supply (1 site each).

4.3.3 Technical Evaluation

4.3.3.1 Geology

The Lower Gunnison Candidate Area is underlain by the Mancos Shale in thicknesses ranging from zero, along the southwestern margin, to about 3000 feet in the northeastern part of the area, based on structure contour mapping by Cashion (1973), and Williams (1964). The Mancos Shale is gently inclined at about one degree to five degrees to the northeast. The nearest mapped faults, associated with the northeast flank of the Uncompahgre Uplift, are several miles west of the area.

Erosive forces vary throughout the area. Gullying has occured in association with some ephemeral drainages, whereas other areas are relatively stable, particularly the pediment surfaces.

Mineral resources which occur in the Lower Gunnison Candidate Area include oil, natural gas, coal, sand and gravel. A small oil and gas field, the Whitewater Field in T2S, R2E, is the only mineral resource currently under development. Coal in the Dakota Sandstone underlies the area at depths ranging from about 100 to 3000 feet. There are no known Dakota coal beds of commercial interest within the candidate area. Sand and gravel resources occur in terraces along the Gunnison River and in pediment deposits below Grand Mesa. Some of the deposits contain well-indurated clasts of basalt that have excellent engineering characteristics. The value of deposits in any particular area is diminished by the relative abundance of similar-quality material throughout the region and is related to the proximity of the deposit to areas of intended use.

4.3.3.2 Hydrology

The Lower Gunnison Candidate Area is in the lower portion of the Gunnison River Basin. All surface water from the area flows into the Gunnison River within 20 miles of its confluence with the Colorado River. Principal drainages, which flow generally westward into the Gunnison River, are, from south to north, Deer Creek, an ephemeral stream, and Indian and Kannah Creeks. Sink Creek flows northwesterly into the Orchard Mesa Canal, which is in the extreme northern part of the candidate area. Juniata and Perdy Mesa Reservoirs are major water sources for Grand Junction. Cheney Reservoir, used for stock watering, is of importance due to its proximity to the Cheney Reservoir site.

Flood potential is very low for most of the Lower Gunnison Candidate Area. The Gunnison River has carved a canyon along most of the western side of the area and its floodplain is generally of limited areal extent. The area of high flood potential is also confined to the immediate vicinity of other creeks, washes and gullies. Large interfluvial areas predominate, where the flood potential is very low.

Water quality tests for the Gunnison River indicate that ground water recharge has the most significant effect on water quality within the candidate area. At Delta, the applicable standards are met by all average concentrations, but the maximum concentrations of zinc, selenium, cadmium, lead and manganese exceed the standards. Between Delta and Grand Junction, the concentrations of most constituents increase.

Only minor amounts of poor quality water are produced from the Mancos Shale. This water is usually associated with fracture zones. The first underlying important aquifer is the Dakota Sandstone, which occurs at about 100 to 3000 feet below the surface. The depth to the Dakota Sandstone generally increases from west to east within the candidate area. Only five registered water wells are within the candidate area. Four shallow wells, less than 100 feet deep, are located in T2S, R2E. A 500 foot well is located in section 4, T3S, R2E.

4.3.4 Representative Site Description - Cheney Reservoir Site

4.3.4.1 General Site Description

4.3.4.1.1 Location

The Cheney Reservoir site is located in the southeast part of Grand Valley in Mesa County (Figure 21). It is 17 miles southeast of Grand Junction, 8.5 miles southeast of Whitewater, and 4 miles north of the Mesa-Delta County line. U.S. Hwy. 50 provides access to within three miles of the site. The site covers about one square mile in sections 11, 12, 13, and 14, T3S, R2E (Figure 22).

4.3.4.1.2 Topographic Setting

The Cheney Reservoir site is situated on the western slope of Grand Mesa at the head of a low pediment surface that gently slopes to the southwest toward the Gunnison River. Elevation ranges from about 5200 to 5400 feet. The pediment surface forms a drainage divide between two small ephemeral washes. One wash is approximately 800 feet north of the site and the other is approximately 1700 feet to the south. These washes merge with Indian Creek 0.1 to 0.5 miles below the site. The drainage divide slopes approximately two percent, and total relief across the proposed disposal area is approximately 60 feet.

4.3.4.1.3 Land Use and Ownership

Land use and ownership of the Cheney Reservoir site is shown on Figures 23 and 24. The site is wholly on public lands administered by the U.S. Bureau of Land Management that are subject to existing oil and gas leases. Cheney Reservoir, about 60 acres in area, is located about one mile south of the site. The reservoir is used for livestock and wildlife watering. Primary use of the site is for grazing purposes.

A transmission line within a 75 foot right-of-way crosses the site in a general north-south direction. Another transmission line crosses east of the site. Application has been submitted for an underground pipeline which would extend near a portion of the south side of the site.

The site is within the drainage basin of the proposed Dominquez Reservoir, the dam of which is located one mile upstream (southerly) along the Gunnison River from Whitewater. Surface drainage from the Cheney Reservoir site is westerly into Indian Creek, which flows into the Gunnison River about three miles above the dam site. An irrigation ditch crosses the upper part of the site.

Within one mile of the site, to the northeast, there are two trailers (DOE, 1983). A zone of irrigated agricultural land lies between one and two miles from the site in the valley of Kannah Creek near Smith Ditch. Associated with this zone are farmsteads, ranches, and some trailer homes. Most of the irrigated agricultural land is two to three miles from the site, and there are more farmsteads and ranches in this zone. Between two and three miles northeast of the site there are at least eleven single-family homes and two trailers. Except for the agricultural lands in the Kannah Creek valley, most of the land within three miles of the site is rangeland.

4.3.4.2 Technical Evaluation

4.3.4.2.1 Geology

The Cheney Reservoir site is underlain by sediments that rest on a pediment slope produced by erosion of the Mancos Shale on the lower slope of Grand Mesa. The site is underlain by about 300 to 700 feet of Mancos Shale, based on structure contour mapping by Williams

(1964). Shale thickness increases from southwest to northeast. The site is on a broad homocline that separates the Uncompahgre Uplift from the Book Cliffs Monocline. No bedrock exposures occur on site, but rock dips beneath the site are probably around one to three degrees to the northeast, based on regional trends. The nearest mapped faults are several miles away and are associated with the northeast flank of the Uncompahgre Uplift.

At least 10 to 30 feet of Mancos Shale was penetrated in each of six borings at the site (DOE, 1983). At the point of contact between the overlying soil and the bedrock, the Mancos Shale is weathered to the point of having an almost soil-like texture. Within a few feet, however, the shale becomes relatively fresh, changes to an olive-gray color, and becomes noticeably fractured, many of the fractures being filled with gypsum. With increasing depth (the maximum depth explored was 50 feet), the fracturing diminishes and the shale becomes relatively impermeable. The permeability of the shale is typically in the range of 1×10^{-6} centimeters per second or less.

The thickness of the near surface deposits, which consist primarily of alluvial deposits (Figure 22), ranges from about 23 to 42 feet. These deposits consist of interlayered clay, silt, sand, and gravel with occasional layers of basalt cobbles and boulders (SHB, 1985b). This layer apparently represents mixed alluvial and debris flow deposits.

The soils at the Cheney Reservoir site consist of a light grayish-tan to brown sandy silt with occasional clay zones and with gravel, cobble, and boulder-size fragments of basalt. The percentage of gravel, cobble, and boulder-size material varies greatly; some zones, a few feet thick, are relatively free of coarse material, whereas in others as much as 25 to 50 percent of the material is rock fragments. The soils are resistant to surface erosion, and this is evidenced by the smoothness of the site and the absence of major drainages.

Sheet wash and rill wash are the primary erosive forces currently active on the Cheney Reservoir site (Figure 25). Several ephemeral washes draining from the higher elevations are present on and near the site. Drainages on the site are occasionally incised to depths of five feet or more and a few have steep banks indicative of rapid erosion. The remainder of the site area is relatively stable as indicated by the relatively smooth, undissected nature of the site. Erosion of the ephemeral gullies on the site appears to be the major geomorphic hazard at the Cheney Reservoir site.

Very few wells have been drilled to explore the Cheney Reservoir area for oil and gas. A successful gas well was drilled a few miles northeast of the site.

Coal in the Dakota Sandstone may underlie the site at depths of about 300 to 800 feet. Dakota coals are usually thin and are probably not of any economic significance beneath the Cheney Reservoir site.

The gravel at the site has a low economic value at present because it is not located near any major planned development and it is generally uniformly distributed in a matrix of sandy silt and clay. Removal of the matrix material from the gravel would be expensive, and much cleaner deposits closer to development areas are currently available.

4.3.4.2.2 Hydrology

The Cheney Reservoir site is on a drainage divide with a very small area topographically above it. The potential for serious flooding on site is low. The small washes that drain the Cheney Reservoir site merge with Indian Creek 0.1 to 0.5 miles west of the site. Indian Creek flows into Kannah Creek four to five miles downstream from this junction, and Kannah Creek empties into the Gunnison River about two miles below its confluence with Indian Creek. The closest important surface waters to the site are Indian Creek and Cheney Reservoir, about 0.8 miles from the site.

No surface water quality data exists for the ephemeral streams in the vicinity of the Cheney Reservoir site. Limited data exist for Kannah Creek and the Gunnison River downgradient from the site. The results of measurements at Delta, approximately 25 miles upstream from the site, show that the applicable drinking water standards are met by all average concentrations, but that the maximum concentrations of zinc, selenium, cadmium, lead, and manganese exceed the standards. Between Delta and Grand Junction, the concentration of most constituents increases.

The Juniata and Perdy Mesa Reservoirs, the main sources of water for the city of Grand Junction, lie upstream from the site. The water-supply intake in the Gunnison River, used by the City of Grand Junction during dry periods, is approximately ten miles downstream from the confluence of Kannah Creek and the Gunnison River. The confluence of the Gunnison and Colorado Rivers is one mile farther downstream.

Field programs conducted by the U.S. Department of Energy have involved exploratory drilling, hydraulic testing, monitoring well installation, and water sampling.

These field investigations at the Cheney Reservoir site revealed that:

1. The surficial materials are approximately 30 to 40 feet thick. These materials have an average saturated hydraulic conductivity of approximately 1×10^{-5} centimeters per second.

2. There is a perched lens of ground water in the surficial material overlying the bedrock. Two bedrock wells completed at 50 and 100 foot depths were dry, while the well completed at a depth of 50 feet in surficial materials contains water.

3. The quality of the perched ground water is variable.

Local ground water flow generally parallels the local slope of the land surface to the west. This system is probably recharged by seepage from a ditch which is approximately 0.5 miles east of the site. The ditch diverts water from Indian Creek, an intermittent drainage fed by snowmelt on Grand Mesa. Discharge of the local ground water system is not known, but may occur as underflow to an ephemeral reach of Indian Creek southwest of the site.

Water quality of the shallow ground water ranges from good to poor, exhibiting a definite decrease in quality related to distance from the recharge source. Based on measurements of electrical conductivity, it is believed that concentrations of total dissolved solids (TDS) in the water in the ditch are less than 250 mg/l. The farthest upgradient well has concentrations of TDS ranging between 650 and 1000 mg/l. This upgradient well is approximately 2400 feet from the recharge source. A downgradient well approximately 3300 feet from the ditch or recharge source had a measured TDS concentration of 3746 mg/l, although it was not certain that the TDS concentration was representative of ground water quality.

Only minor amounts of generally poor quality water are produced from the Mancos Shale, host rock for the Cheney Reservoir site (Boettcher, 1972; Lohman, 1965). This water is usually associated with fractured zones. The first underlying potentially important aquifer is the Dakota Sandstone, some 300 to 700 feet below the surface. Water in the Dakota may be brackish or contaminated by hydrocarbons.

There is no known existing use of ground water in the immediate vicinity of the site. The closest known registered wells are about two miles away from the site along Kannah Creek. As of November 16, 1981, the records of the Colorado Division of Water Resources indicate that the nearest registered water well to the site is about 2.5 miles northwest of the site. This well, permit number 19466, was drilled on 6/29/64 to a depth of 506 feet for F. Bradbury. It is located in SW 1/4 NW 1/4, section 4, T3S, R2E. Twelve permitted wells are within six miles of the Cheney Reservoir site. Five of the wells are deep bedrock wells. The nearest of these to the site is three miles away. The nearest shallow well is approximately 3.5 miles northeast of the site on the North Fork of Kannah Creek between Reeder and Hollenbeck Reservoirs.

No decreed springs appear in the records of the State Engineer for the area immediately around the Cheney Reservoir site.

4.4 Grand Hogback Candidate Area

4.4.1 Previous Investigation

Material for this section was derived extensively from four basic sources: Colorado Geological Survey (1982) and U. S. Department of Energy (DOE) (1983, 1986a, 1986b). These sources, part of the Uranium Mill Tailings Remedial Action Program (UMTRAP), are referenced only in instances where specific studies are described. Other sources are referenced wherever used.

4.4.2 General Description

4.4.2.1 Location

The Grand Hogback Candidate Area is located in parts of northern Mesa and central Garfield Counties along the I-70/U.S. Hwy. 6 corridor

(Figures 1 and 26). The area is further defined by occurrences of surface or near-surface exposures of the Wasatch Formation throughout most of the area, in addition to a narrow band of Mancos Shale on the north and east side of the Grand Hogback. The candidate area is a curved elongate area approximately 90 miles long and 40 miles wide. Rifle is the largest town in the vicinity of the candidate area, which is situated between Glenwood Springs and Grand Junction.

4.4.2.2 Topographic Setting

The primary physiographic elements of the Grand Hogback Candidate Area are Grand Mesa and Battlement Mesa to the south, the Roan Plateau on the north and northwest, the Grand Hogback, which forms the eastern side of the Piceance Basin, on the northeast side, and the Colorado River Valley, running through the center. The candidate area is in the southeastern part of the Piceance Basin.

Relief across the area is large, with elevations ranging from about 5500 feet along the Colorado River to over 9000 feet in parts of the Roan Plateau and almost 11,000 feet on Battlement Mesa. In many areas, where cliff-forming geologic units are present at canyon rims, the relief is extremely large. The Wasatch Formation is generally a slope-forming unit due to its abundance of shale, so areas where it is exposed at the surface have relatively low relief. Slopes greater than ten percent are common in areas of Wasatch exposure or where the Wasatch occurs near the surface below surficial materials.

All creeks in the candidate area flow into the Colorado River, which flows through the center of the area generally along the highway and railroad corridor in a relatively flat-bottomed valley about five miles wide. Two deeply incised creeks, Roan Creek and Parachute Creek, flow southward from the Roan Plateau into the Colorado River. Drainages south of the river, on the slopes of Grand and Battlement Mesas, are more closely spaced and of lower relief. Among these are Maroon Creek, Beaver Creek, Battlement Creek and Wallace Creek.

4.4.2.3 Land Use and Ownership

All of the potential sites are on public domain lands. These lands are administered by the U.S. Bureau of Land Management (BLM), which controls approximately 30 percent of all land in the Grand Hogback Candidate Area (Figure 26). A majority of the land within the candidate area is under the jurisdiction of the U.S. Forest Service. Most privately owned land is along the Colorado River.

The primary land use in the Grand Hogback Candidate Area is grazing. All BLM lands are subject to existing oil and gas leases, and many in the northern part of the area are part of large federal oil shale land withdrawals.

4.4.2.4 Potential Sites

Four potential sites are located in the Grand Hogback Candidate Area (Figure 26). These are Estes Gulch, the representative site, and Lucas Mesa, Flatiron Mesa and Pyramid Rock sites. Five other sites were considered to have suitable or potentially suitable formations and slope characteristics but are not recommended for other reasons. The reasons for eliminating these areas from further consideration were: irrigated agricultural land and a growth area (3 sites each), close proximity to a populated area, severe transportation hazards, steeply dipping bedrock, and insufficient size (2 sites each), and proximity to a fault, proximity to a reservoir, critical ground water recharge area and severe erosion potential (1 site each).

4.4.3 Technical Evaluation

4.4.3.1 Geology

The Grand Hogback Candidate Area is defined by the outcrop area of the Wasatch Formation and a thin band of Mancos Shale between Glenwood Springs and Grand Junction. About 95 percent of the candidate area is underlain by near-surface deposits of the Wasatch Formation, an interbedded sequence of shale, siltstone, and sandstone of early Tertiary age up to 5000 feet thick. The Wasatch lies between the Tertiary Green River Formation and the Cretaceous Mesaverde Group. The Wasatch Formation has been classified as "potentially suitable" because of the sandstone present in the formation. The Wasatch Formation has been divided into three members by Donnell (1961). Shale and claystone dominate the lower and upper members, whereas the middle member is primarily sandstone. The potential sites are in the upper Shire member of the Wasatch Formation. The Mancos Shale is at or near the surface in a thin band along the northeast side of the Grand Hogback. No potential sites are located in the Mancos Shale.

The candidate area is within the Piceance Basin, which is separated from the White River Uplift on the northeast by the Grand Hogback Monocline. A few minor faults occur along the Grand Hogback Monocline, northwest of Rifle and southwest of Glenwood Springs, but none of any significance occur in the candidate area. Several minor folds have been mapped within the candidate area which are also of little significance (Cashion, 1973; Tweto and others, 1978).

Surficial materials commonly consist of terrace gravels in low-lying areas peripheral to the Colorado River and pediment gravel deposits along slopes at the base of upland areas north and south of the river. The potential sites are all located in areas of surficial pediment gravels, where erosive potential and geologic hazards are lower than in surrounding areas. These important factors are highly variable within the Grand Hogback Candidate Area. Suitable areas are located where sheet and rill wash are dominant, erosion potential is moderate, slopes are not potentially unstable, slope retreat is low and destruction by landsliding is not imminent. These sites are determined by a careful review of existing mapping of surficial and bedrock geology, geomorphic features and geologic hazards (Cashion, 1973; Tweto and others, 1978; Soule and Stover, 1983), followed by site-specific investigations.

The Grand Hogback Candidate Area contains abundant mineral resources, however, none appear to conflict with the use of any of the potential sites for waste disposal. Two relatively large and twelve smaller oil and gas fields are scattered throughout the area (Scanlon, 1983). These are the Ruleson, Plateau, Dry Fork, Hancock Gulch, Logan Wash, Coon Hollow, Bronco Flats, Horsethief Creek, Buzzard, Buzzard Creek, Vega, Sheep Creek, Hells Gulch and Mam Creek fields. No oil and gas wells are located within the potential sites.

Coal resources underlie the entire candidate area, but the seams are either too thin or at too great a depth to be of commercial value. Thin coal beds of the Dakota Sandstone occur at depths in excess of 5000 feet. Mesaverde coals have been mined along the Grand Hogback, (Turney and Murray-Williams, 1984) but due to the steep dips the coal beds are greater than 500 feet deep several miles into the Piceance Basin where potential sites are located.

Valuable oil shale resources are found in the northern part of the candidate area within the Green River Formation along the Roan Cliffs. Since these deposits occur above the Wasatch Formation, none of them underlie potential sites.

Potential gravel sources are present in the candidate area. These gravels would probably be adequate for riprap used for the waste disposal facility. Depending on the amount of gravel excavated, there may be enough material to backfill drainages below the site to prevent further erosive incision. The pediment gravels probably do not contain significant sources of sand.

4.4.3.2 Hydrology

The most important surficial water body within the Grand Hogback Candidate Area is the Colorado River, which flows generally southwestward through the center of the area. Creeks which feed the Colorado River are discussed in Section 4.4.2.2. Rifle Gap Reservoir, just north of the Grand Hogback, is the only large lake in the area. Several springs occur in the Roan Cliffs. Flood potential is low for most of the candidate area, except in the isolated low lying areas, especially along the Colorado River. All potential sites are located in areas of low flood potential.

The surficial pediment gravels that underlie the potential sites probably carry little or no water. At certain times of the year following periods of heavy precipitation, minor amounts of water may infiltrate into the gravel. Localized perched ground water zones may also exist seasonally within the surficial deposits or at the surficial/bedrock contact.

Debris-flow deposits contain phreatic water at depths of about 50 feet below land surface. Wells completed in these deposits yield approximately 15 gpm (Wright Water Engineers, 1979). Basalt flows contain water at depths of about 200 feet below land surface. Wells completed in the basalt yield approximately 15 gpm (Colorado Water Resources Department, 1973).

Ground water within the Wasatch Formation is confined by the low permeability shales and claystones which are interbedded with the more permeable sandstones. The Wasatch Formation has highly variable ground water characteristics (Repplier and others, 1981). In some areas the Wasatch yields virtually no water, but other wells may produce over 100 gpm. The only published information on the aquifer characteristics of the Wasatch Formation are very brief and sketchy. Based on preliminary observations in the area, it appears as though the upper member (Shire member) and lower member (Atwell Gulch member) of the Wasatch generally produce only minor amounts of water, whereas the middle member (Molina member) is capable of producing large amounts of water. Water in the Wasatch Formation is reportedly often poor in quality and may be contaminated with hydrocarbons.

According to the records of the Colorado Division of Water Resources, there are over 450 registered water wells in the vicinity of the Grand Hogback Candidate Area. Most of these are in the vicinity of the Colorado River near towns and are shallow wells in river alluvium. Over 200 wells are within 5 miles of Silt and over 100 are in the Rifle area. Very few of these water wells are developed in the Wasatch Formation.

4.4.4 Representative Site Description - Estes Gulch Site

4.4.4.1 General Site Description

4.4.4.1.1 Location

The Estes Gulch site is located approximately 5 miles north of Rifle and 1.5 miles southwest of the Grand Hogback Monocline in Garfield County. It is within half a mile of State Hwy. 13-789 and about six miles north and northwest of the junction with U.S. Hwy. 6 in Rifle. The site is a rectangular area of about 400 acres within the west-central part of section 14, T5S, R93W (Figure 26).

4.4.4.1.2 Topographic Setting

The Estes Gulch site is located on a gently south-sloping pediment surface. The pediment surface is bounded on the north by exposures of the Shire member of the Wasatch Formation along a southwestern slope of the Grand Hogback as well as by some landslide deposits. It is dissected by Estes Gulch southeast of the site. Southwest slopes toward Government Creek bound the pediment surface on the south and west. Deeply cut drainages on both sides of the site cut it off from upland drainage. Total relief is about 120 feet across the site, with slopes of less than five percent. Areas with slopes of more than ten percent are common in the vicinity of the site (Figure 27).

4.4.4.1.3 Land Use and Ownership

The Estes Gulch site is entirely on public lands administered by the U.S. Bureau of Land Management (Figure 28). The site is within a BLM grazing allotment and used for sheep and cattle grazing. The land containing the site is also under oil and gas leases.

The site is entirely surrounded by BLM lands, however, several blocks of privately owned land exist within 0.2 miles to the west and south, along State Hwy. 13-789. Private land is abundant to the south and east of the site (Figures 28 and 29) and Rifle Gap State Park is less than 1.5 miles northeast of the site. Two 40 acre areas north of the site are part of federal oil shale reserves.

4.4.4.2 Technical Evaluation

4.4.4.2.1 Geology

Approximately 3000 to 5000 feet of the Wasatch Formation has been measured in sections northwest of Rifle by the U.S. Department of Energy (DOE) (1983). The thickness of the Wasatch at the Estes Gulch site is not known, but is estimated to exceed 1000 feet. Five soil boreholes drilled by the U.S. Department of Energy in October 1985 penetrated shales and siltstones of the Shire Member of the Wasatch Formation at depths of up to 260 feet. The site lies about 1.5 miles southwest of the Grand Hogback Monocline, a major regional structure which forms the boundary of the Piceance Basin. Bedrock in the site area is estimated to dip between 15 degrees to the southwest and near vertical (DOE, 1986b).

Two relatively large areas within the site contain surficial deposits that rest on a pediment surface, formed on the Wasatch Formation. The surface is about 50 feet above Estes Gulch, an adjacent ephemeral stream, and about 200 feet above Government Creek, the primary creek in the area. At the Estes Gulch site, the Wasatch Formation is generally overlain by 15 to 40 feet of surficial deposits (DOE, 1986b). Surficial materials which surround the site are shown in Figure 27. The Wasatch Formation is exposed in small portions of the site area. Terrace deposits, landslide deposits, colluvium and slopewash deposits, as well as surficial exposures of the Wasatch surround the pediment areas of the site.

Sheet and rill wash are the dominant erosive forces within the site with accompanying gully erosion. Soule and Stover (1983) classified the pediment areas of the site as having no major geologic hazards (Figure 30). The site however, must be considered as having a moderate erosion potential. Surrounding areas are classified as potentially unstable slopes, primarily above the site to the north, and a physiographic flood plain along Government Creek south of the Estes Gulch site.

The nearest mapped fault is located about three miles northwest of the site (Tweto and others, 1978). A fault analysis was performed in 1985 by the DOE using low sun angle photographs (DOE, 1986), but the results of this study are currently unavailable. Due to the proximity of the site to the Grand Hogback Monocline, older faults may be present beneath the site.

No important mineral deposits apparently underlie the Estes Gulch site. Oil and gas, coal, oil shale, and sand and gravel resources occur in the vicinity of the site, however.

The nearest oil and gas well is about 1.5 miles from the site, in section 10 of the same township. No major fields are in the immediate vicinity of the site.

Coal is not mineable below the site due to the depth to the Mesaverde coal beds. Coal beds in the Dakota Sandstone may also exist at great depth and are also uneconomic. Within two miles north and northeast of the site, 14 coal mine openings and 9 named coal mines have operated in the past (Turney and Murray-Williams, 1983). These mines exploited Mesaverde coals along the Grand Hogback.

Isolated federal oil shale reserves are located near the site in all directions, the closest being within one mile. The main Naval Oil Shale Reserve is about seven miles to the northwest. The oil shale is derived from the Green River Formation, stratigraphically above the Wasatch, so no oil shale reserves underlie the Estes Gulch site.

Soule and Stover (1983) mapped potential gravel resources (Upland pediment gravels) northwest of the site. These are considered to have a significant amount of fine material and therefore to be of marginal value. The surficial materials at the site are of low economic value.

4.4.4.2.2 Hydrology

The Estes Gulch site is located at the head of a drainage area between two deeply cut drainages, Estes Gulch on the east and an unnamed drainage on the west. Both flow into Government Creek within about 0.5 miles of the southern site boundary, four to five miles upstream from its confluence with Rifle Creek. Rifle Creek flows into the Colorado River about one mile beyond this confluence. The city of Rifle's water supply is from the Colorado River about 1.5 miles upstream from its confluence with Rifle Creek.

The Estes Gulch site lies upgradient from two aquifers, the alluvial aquifer along the Colorado River and the middle member of the Wasatch Formation. Ground water in both aquifers flows generally westward. The quality of background waters in these aquifers is poor (DOE, 1986b). The site is situated about five miles from the alluvial aquifer and several hundred feet above the aquifer in the Wasatch Formation, so it should not impact either one.

Seven monitor wells were installed at the Estes Gulch site (DOE, 1986b). Ground water was encountered in only one, the deepest well, at a depth of 270 feet. Slug tests and chemical analyses were performed, results of which are unavailable at this time.

One water well is located in the same section as the site. A 150 foot well was installed in NW 1/4 NW 1/4, section 15. Another nearby well is in SE 1/4 SW 1/4, section 14. It is a 90 foot well drilled in 1970 for the Colorado Ute Electric Association.

Numerous wells are located in the vicinity of Rifle. These wells are primarily used for irrigation and stock purposes. Only one well, operated by the village of South Rifle, is known to be used for domestic purposes (DOE, 1986b). It is completed in the Colorado River alluvial aquifer and serves approximately 500 people.

5.0 Representative Site Evaluation

Representative sites from each of the candidate areas were evaluated with regards to the limiting criteria presented in Section 2.0 and the numerical rating matrix shown in Figure 31. Representative sites evaluated in this manner include Clifford, Wigwam, Rugby, Two Road, Cheney Reservoir, and Estes Gulch. Rating matricies for each of these sites are represented in Tables 1 through 6.

The numerical rating matrix is designed to evaluate the key technical factors that are important to successful siting of a low-level waste repository. Paramount in these factors is the general geologic setting and hydrogeologic relationships of the representative site. Scores have been assigned to a number of geologic and hydrologic factors. Each factor has been assigned a rank of zero to four in the matrix based on the characteristics of the particular site being evaluated. Some factors are more important than others, so the factors have been weighted from one to three accordingly. Total site scores are calculated by adding all the factor scores for each site.

In general, all sites are located in areas of thick, relatively impermeable shale with very limited ground water resources. Because of this similarity, all sites have a relatively high ranking. Matrix scores for each of the representative sites are as follows:

Two Road	109
Clifford	108
Wigwam	108
Rugby	105
Estes Gulch	94
Cheney Reservoir	84

The matrix scores could range from 0 (an unsuitable site area) to a maximum of 120 (a perfect site area). The Two Road, Clifford, Wigwam, and Rugby sites all rank very high and should be considered as sites with a very high potential for safe, long-term disposal of radioactive wastes. The Estes Gulch site ranks slightly lower because of its proximity to the Grand Hogback and potential for bedrock jointing. Such a factor must be properly investigated during any future studies and any adverse conditions mitigated, if necessary. The Cheney Reservoir site ranks lowest of all the sites because of the thick, permeable surficial materials and presence of a minor amount of ground water in this zone. Special care must be taken to adequately mitigate radionuclide migration from this potential site.

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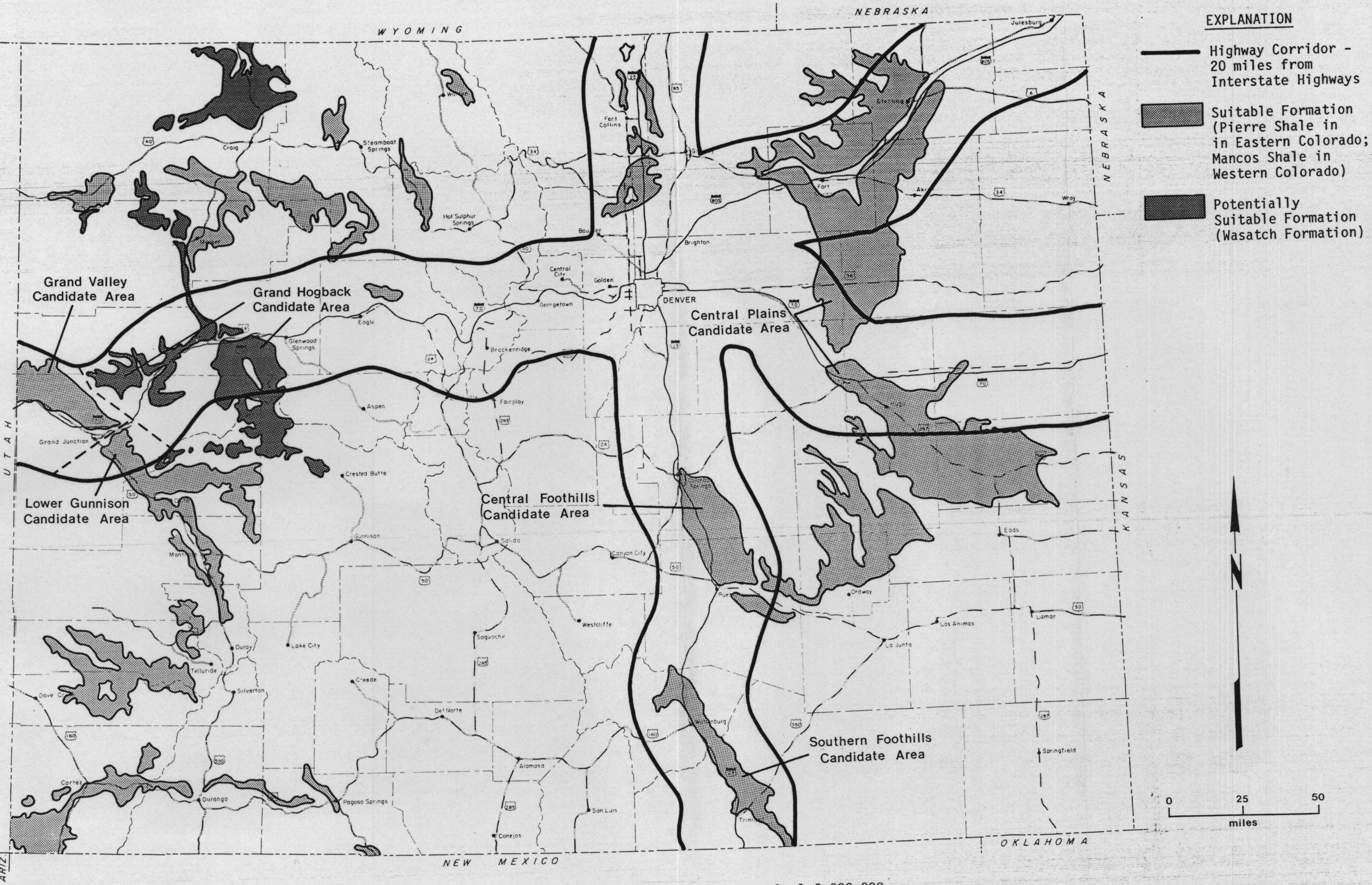

Figure 1. Location Map of the Six Candidate Areas in Colorado, scale 1:2,000,000.

GEOLOGIC AGE	STRATIGRAPHIC UNIT	ROCK DESCRIPTION	APPROXIMATE THICKNESS IN FEET
Miocene	Ogallala Formation*	Chiefly cobbly gravel well cemented with sandy caliche. In places capped by hard, dense, sandy calcrete as much as 12 feet thick.	17-350
Paleocene - Upper Cretaceous	Dawson-Denver-Arapahoe Formations* undivided	Claystone, siltstone, sandstone	1500
Upper Cretaceous	Laramie Formation*	Interbedded siltstone, claystone and shale with sandstones and minor coal bed at bottom 100 ft.	250-350
	Fox Hills Sandstone*	Friable fine-to-medium-grained massive white, or less commonly, yellowish quartz sandstone	200-250
	Pierre Shale	Mostly silty grey and black shale with soft sandstone interbeds dominant in middle zone	2000-5200
	Niobrara Formation	Yellow chalk and thin white limestone; light-gray limestone at base	700
	Carlile Shale	Silty, hard, carbonaceous, gypsiferous, fissile shale	230
	Greenhorn Limestone	Gray limestone	150
	Graneros Shale	Hard silty shale	100
Lower Cretaceous	Dakota Group* undivided	Buff sandstone and conglomeratic sandstone	100-200
Jurassic	Morrison Formation	Varicolored siltstone, claystone, and sandstone containing fossil dinosaur bones	320
Triassic - Precambrian undiff.	Entrada Formation and below	Varies considerably	Varies

(1) See Section 3.4.3.1 for stratigraphy above the Pierre Shale in the Southern Foothills Candidate Area.

* Principal aquifers

Modified from Johnson, 1969; Scott and others, 1978; Sharps, 1980.

Figure 2. Generalized Stratigraphic Section of Eastern Colorado.(1)

GEOLOGIC AGE	STRATIGRAPHIC UNIT	ROCK DESCRIPTION	APPROXIMATE THICKNESS IN FEET
Late Tertiary	Unnamed Basalt	Numerous dark gray, black, and dark red-brown basalt lava flows on Grand and Battlement Mesas. Forms cliffs.	~ 800
		unconformity	
Early Tertiary	Uinta Formation	Tan, gray, and buff siltstone, sandstone, and marlstone.	800-1000
	Green River Formation	Tan to gray calcareous siltstone with dark brownish gray kerogen-rich beds (oil shale). Forms steep slopes and cliffs.	1000-3000
	Wasatch Formation and Ohio Creek Conglomerate	Varigated sandstone, siltstone, shale, mudstone, conglomerate. Forms benches and slopes.	300-5000
		unconformity	
Late Cretaceous	Mesaverde Group	Buff colored sandstones and siltstones with coal beds. Forms cliffs.	1000-5000
	Mancos Shale	Gray and black shale with thin beds of sandstone and limestone. Forms slopes and valley floors.	3000-6000
	Dakota * Sandstone	Sandstone, coaly shale, conglomerate. Forms benches and slopes.	100-225
		unconformity	
Early Cretaceous	Burro Canyon * Formation	Green siltstone, shale, sandstone, conglomerate. Forms benches and slopes.	10-225
Late Jurassic	Morrison Formation	Varicolored claystone, sandstone, siltstone with thin limestone beds. Forms slopes and badlands.	300-600
Middle Jurassic	Summerville Formation	Red and green colored siltstone, mudstone and thin sandstones. Forms slopes.	40-60
	Entrada * Sandstone	White and salmon-red quartz sandstone. Slick Rock member forms cliffs.	75-300
		unconformity	
Late Triassic(?)	Kayenta * Formation	Red and purple siltstone, shale, sandstone, and conglomerate. Forms bench between cliffs.	0-200
Late Triassic	Wingate * Sandstone	Buff and light red sandstone, cross-bedded. Forms steep cliffs.	300-400
	Chinle Formation	Red siltstone, shale, limestone, and conglomerate. Forms steep slopes at foot of cliffs.	80-120
		unconformity	
Precambrian – Proterozoic	Unnamed	Gneiss, schist, granite and pegmatite dikes. Forms floors of canyons in Uncompahgre Plateau.	unknown

Modified from Lohman, 1981; Cashion, 1973; and Tweto and others, 1976.

* Principal aquifers

Figure 3. Generalized Stratigraphic Section of the Grand Junction-Rifle Area.

SURFICIAL GEOLOGY AND SLOPE MAPS

- 10 -	Slope contour line in percent
MD	Mine dump
Ral	Recent Stream Alluvium
Qal	Quarternary Stream Alluvium
	Note: all Q designations are Quarternary age
Qac	Alluvium and Colluvium, Mixed
Qt	Terrace Deposits
Qp	Pediment Deposits
Qls	Landslide Deposits
Qcr	Colluvium and Residuum, Mixed
Qr	Residuum
Qcs	Colluvium and Slopewash Deposits
Qaf	Alluvial Fan Deposits
Qe	Wind Deposited Sand and Silt
Twsh	Tertiary Wasatch Formation, Predominantly Shale
Twss	Tertiary Wasatch Formation, Predominantly Sandstone
Km	Cretaceous Mancos Shale
Kp	Cretaceous Pierre Shale
Kpss	Cretaceous Pierre Shale, Locally Mappable Sandstone Bed
Kn	Cretaceous Niobrara Formation

LAND USE AND OWNERSHIP MAPS

	Site boundary
	Federal land
	State land
	Oil and gas well
	Building
07	Private land with ownership code (see list for owners name)
Clay	Private owners name

GEOLOGIC HAZARDS AND CONSTRAINTS MAPS

SEP	Severe Erosion Potential
HEP	High Erosion Potential
MEP	Moderate Erosion Potential
US	Unstable Slope
PUS	Potentially Unstable Slope
DF	Debris Flow Area
RF	Rock Fall Area
CS	Collapsing Soils
FP	Physiographic Flood Plain
DMA	Debris-flow/Mudflow-Flooding Area
UA	Mine Subsidence Area
UCF	Underground Coal-free Area
	No Hazard

Note: All base maps from U.S.G.S. 7.5 minute quadrangle maps

Figure 4. Explanation Sheet for Individual Site Maps

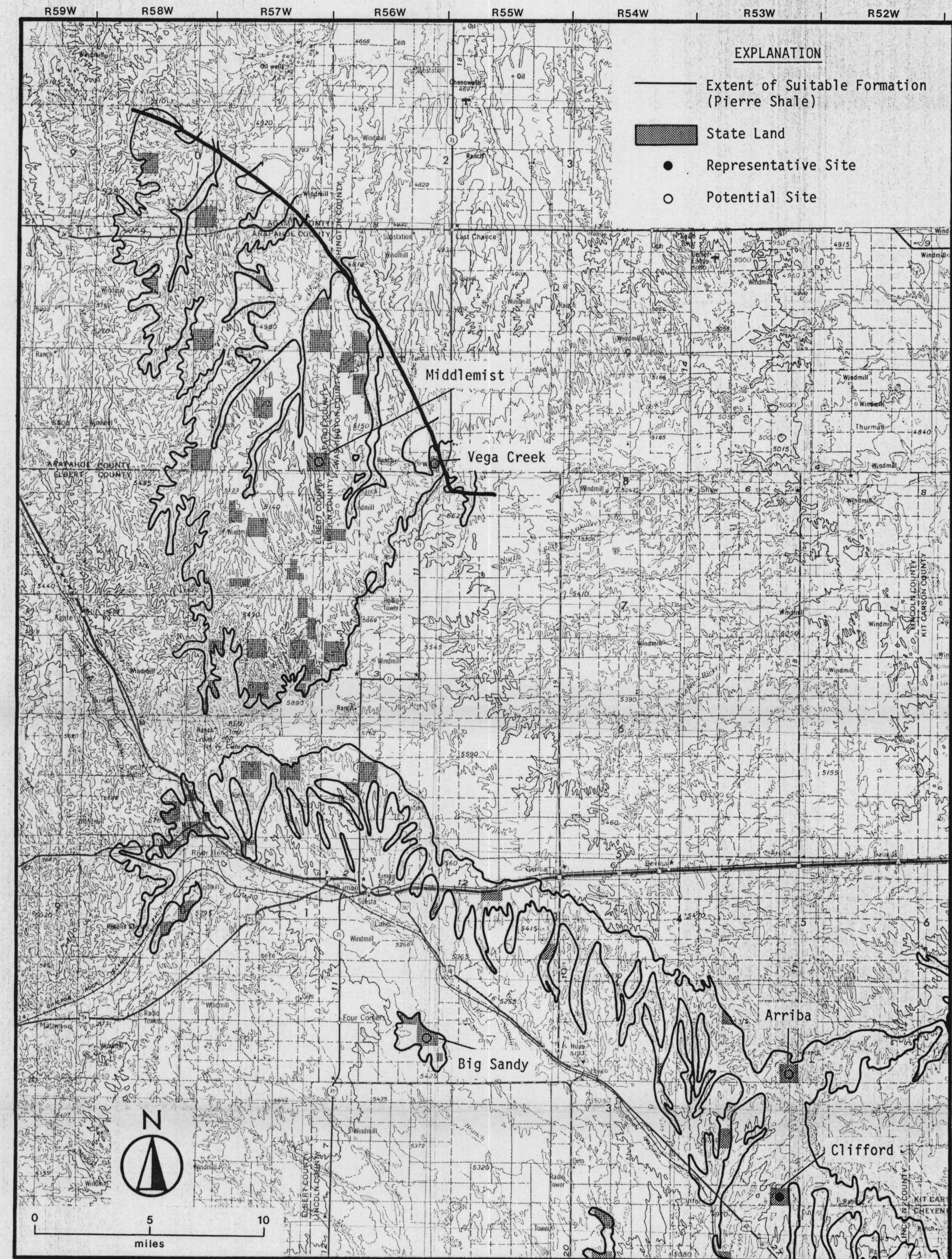

Figure 5. Location Map of the Central Plains Candidate Area, scale 1:300,000.

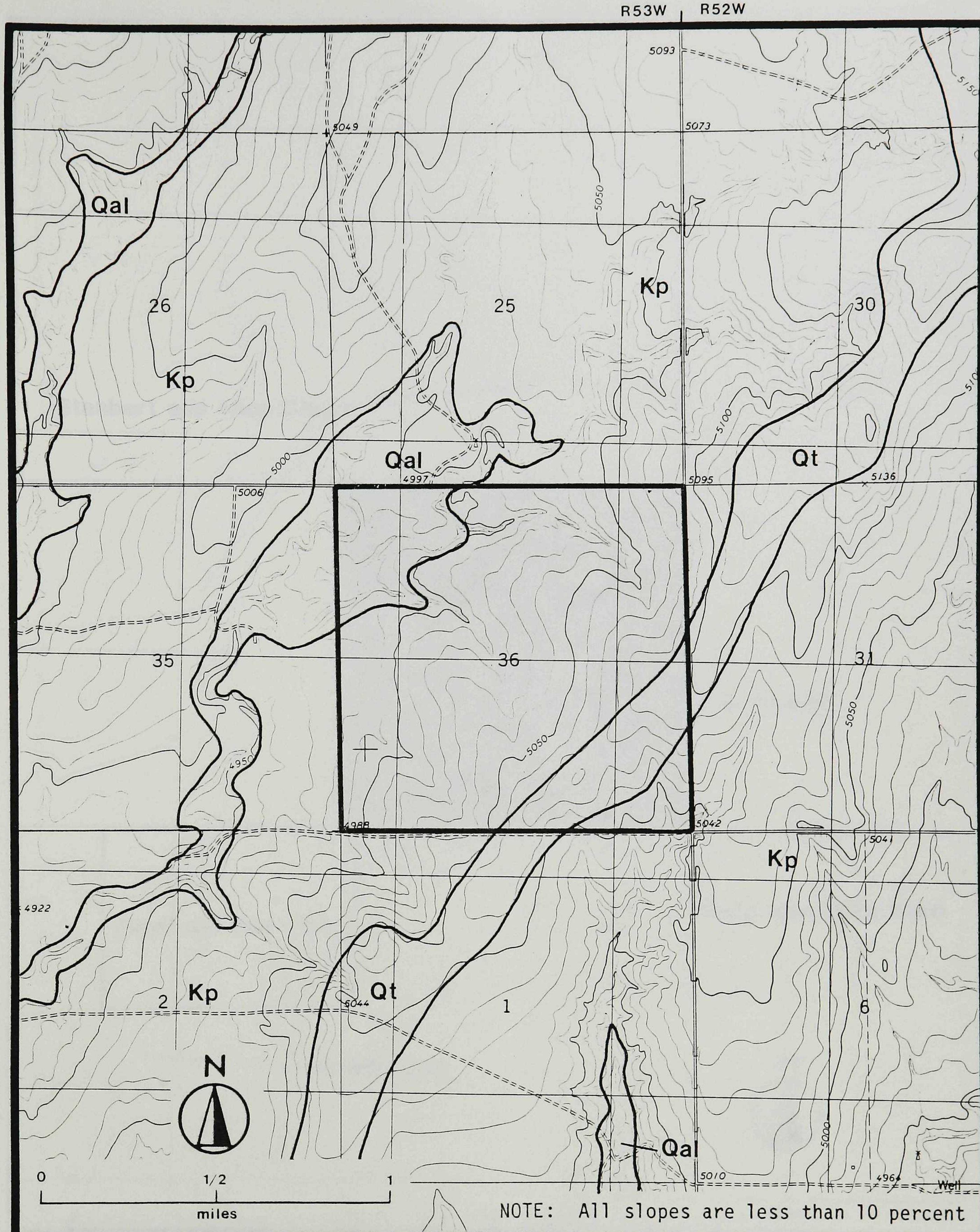

Figure 6. Surficial Geology and Slope Map of the Clifford Site, scale 1:24,000.

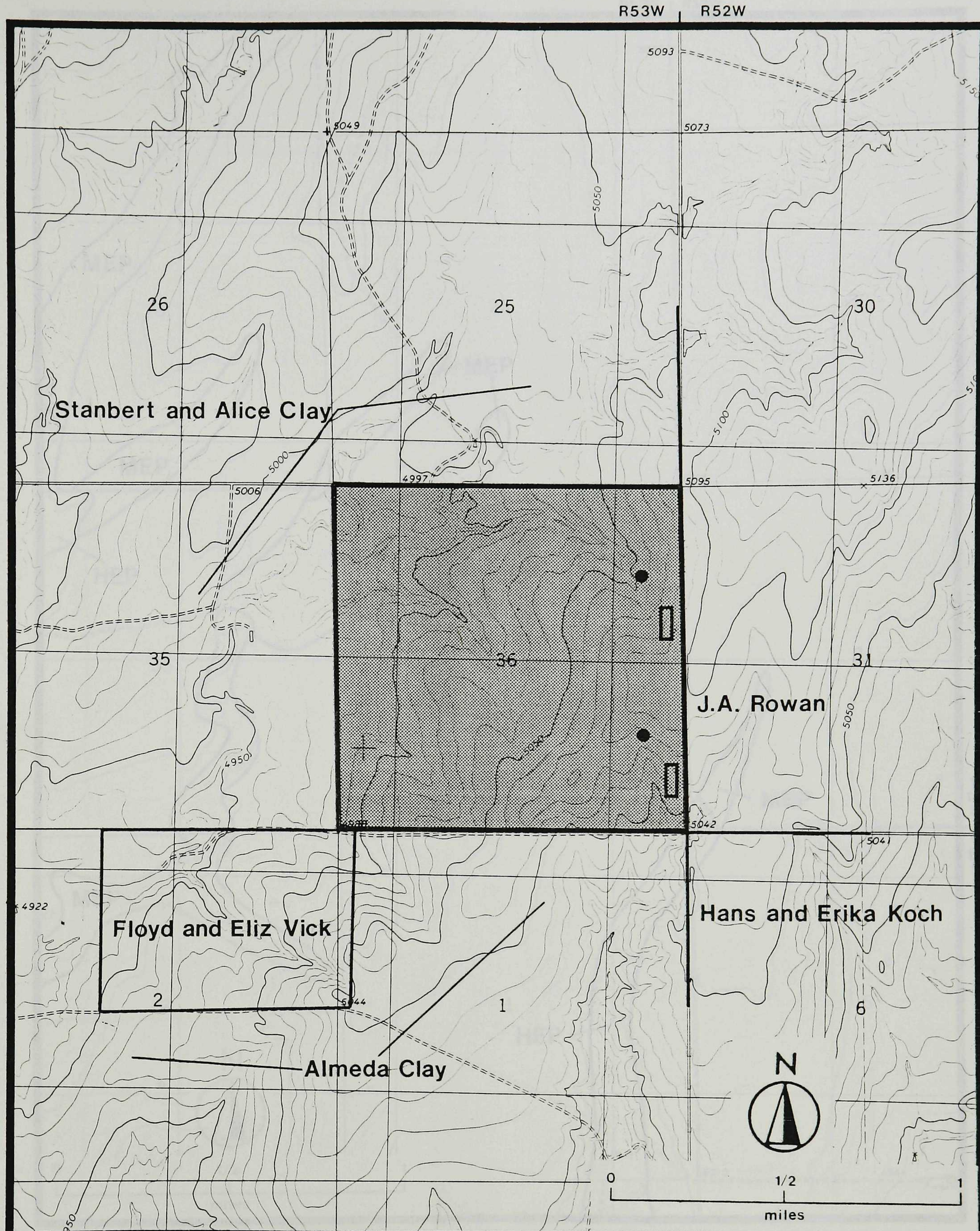

Figure 7. Land Use and Ownership Map of the Clifford Site, scale 1:24,000.

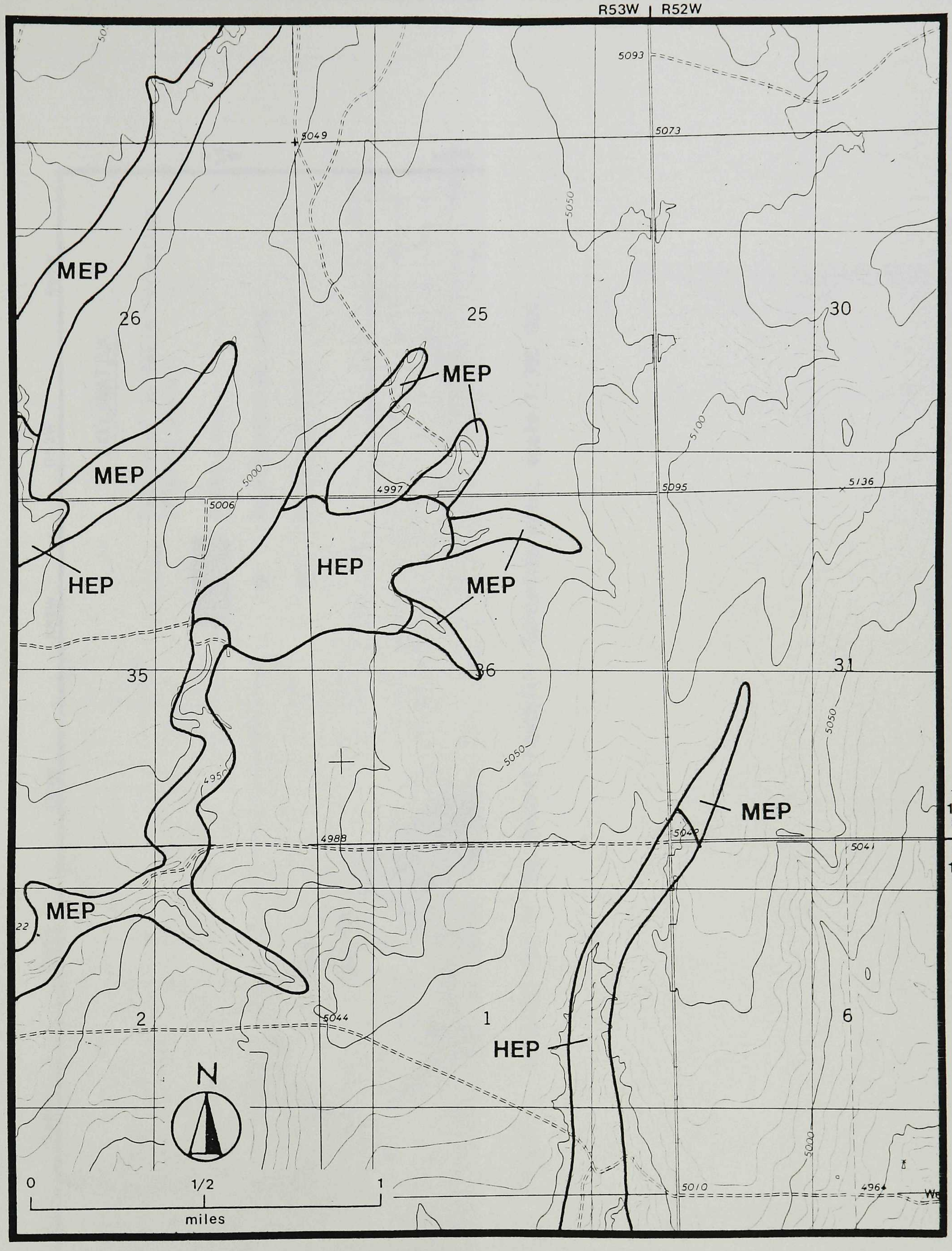

Figure 8. Geologic Hazards and Constraints Map of the Clifford Site, scale 1:24,000.

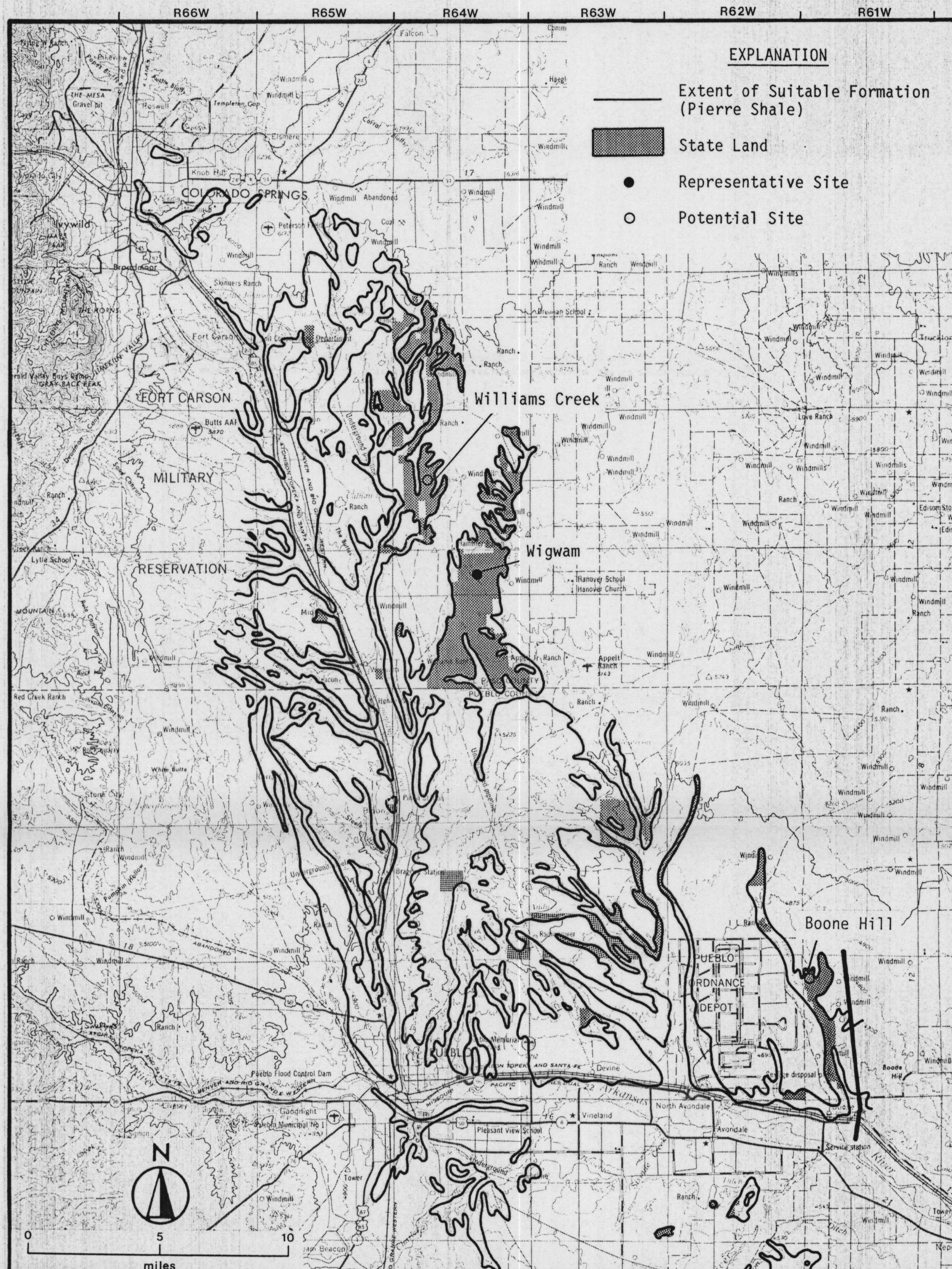

Figure 9. Location Map of the Central Foothills Candidate Area, scale 1:300,000.

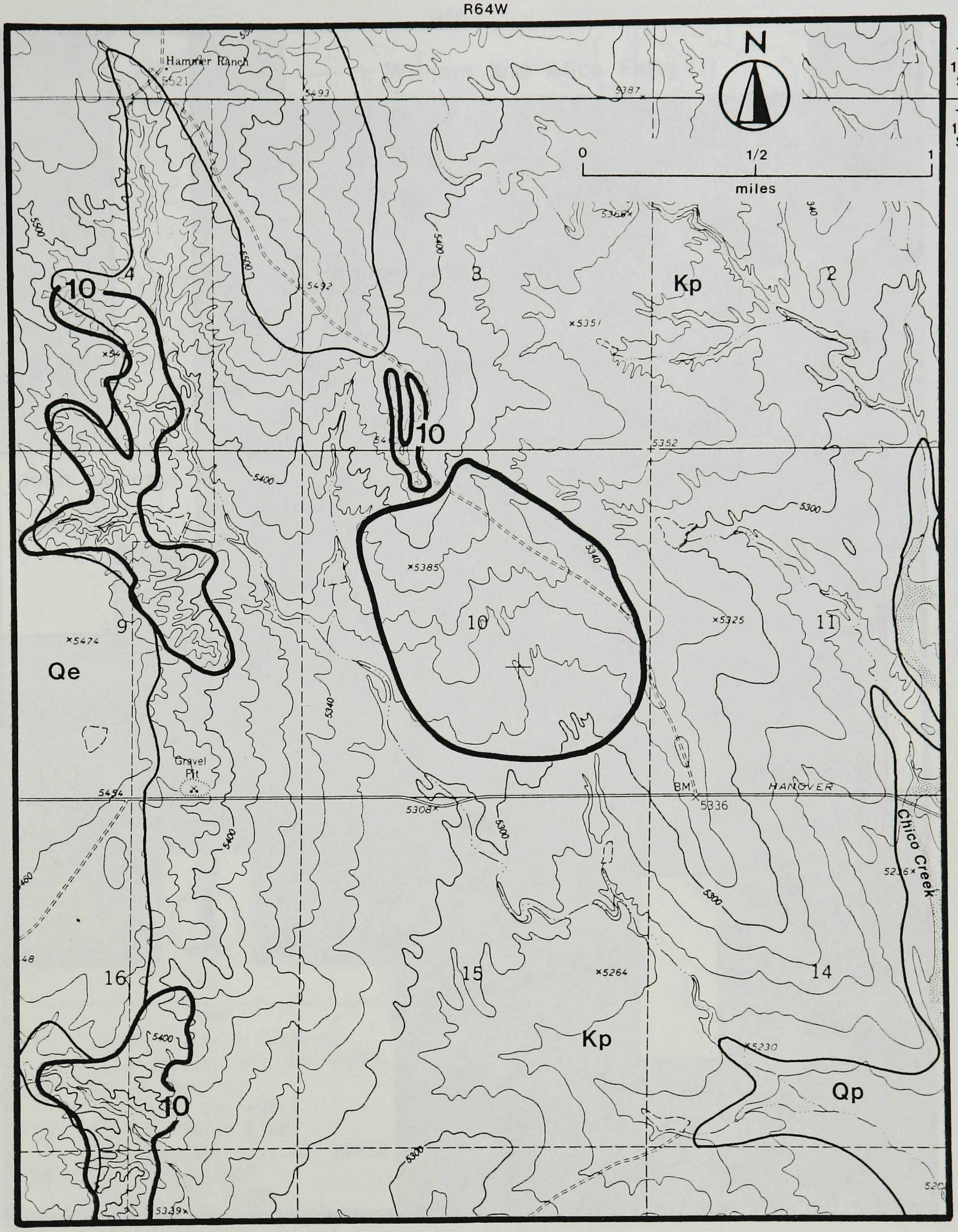

Figure 10. Surficial Geology and Slope Map of the Wigwam Site, scale 1:24,000.

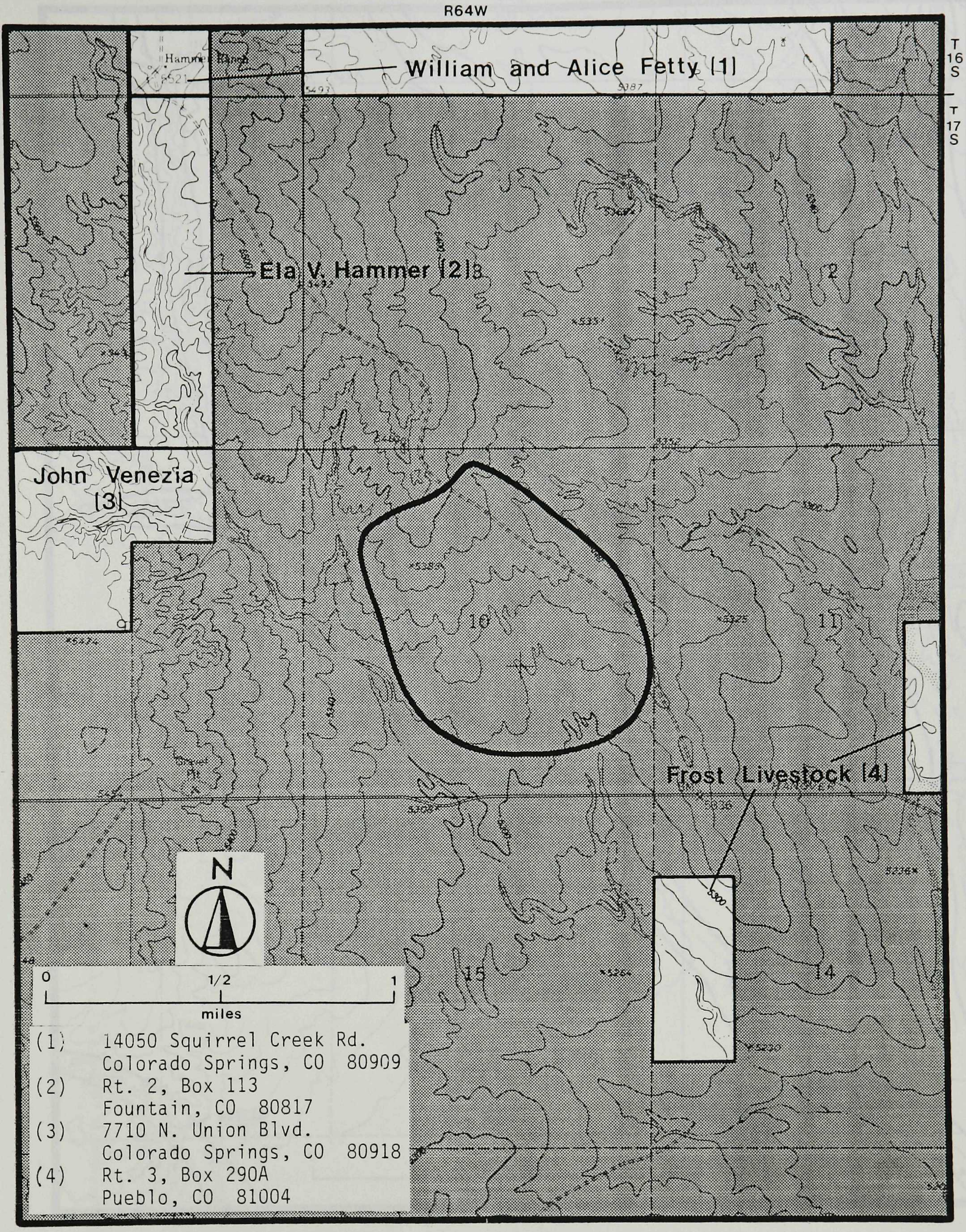

Figure 11. Land Use and Ownership Map of the Wigwam Site, scale 1:24,000.

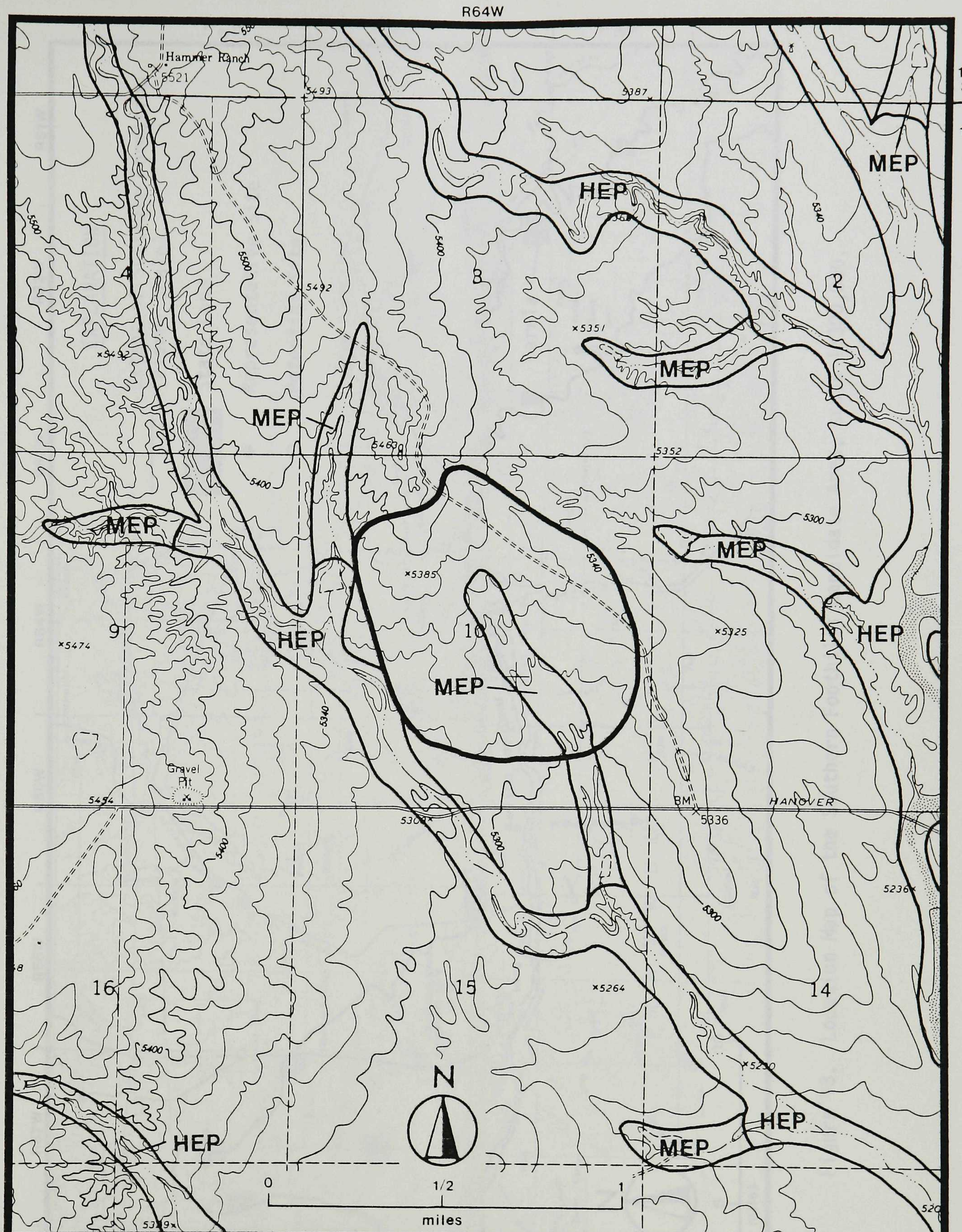

Figure 12. Geologic Hazards and Constraints Map of the Wigwam Site, scale 1:24,000.

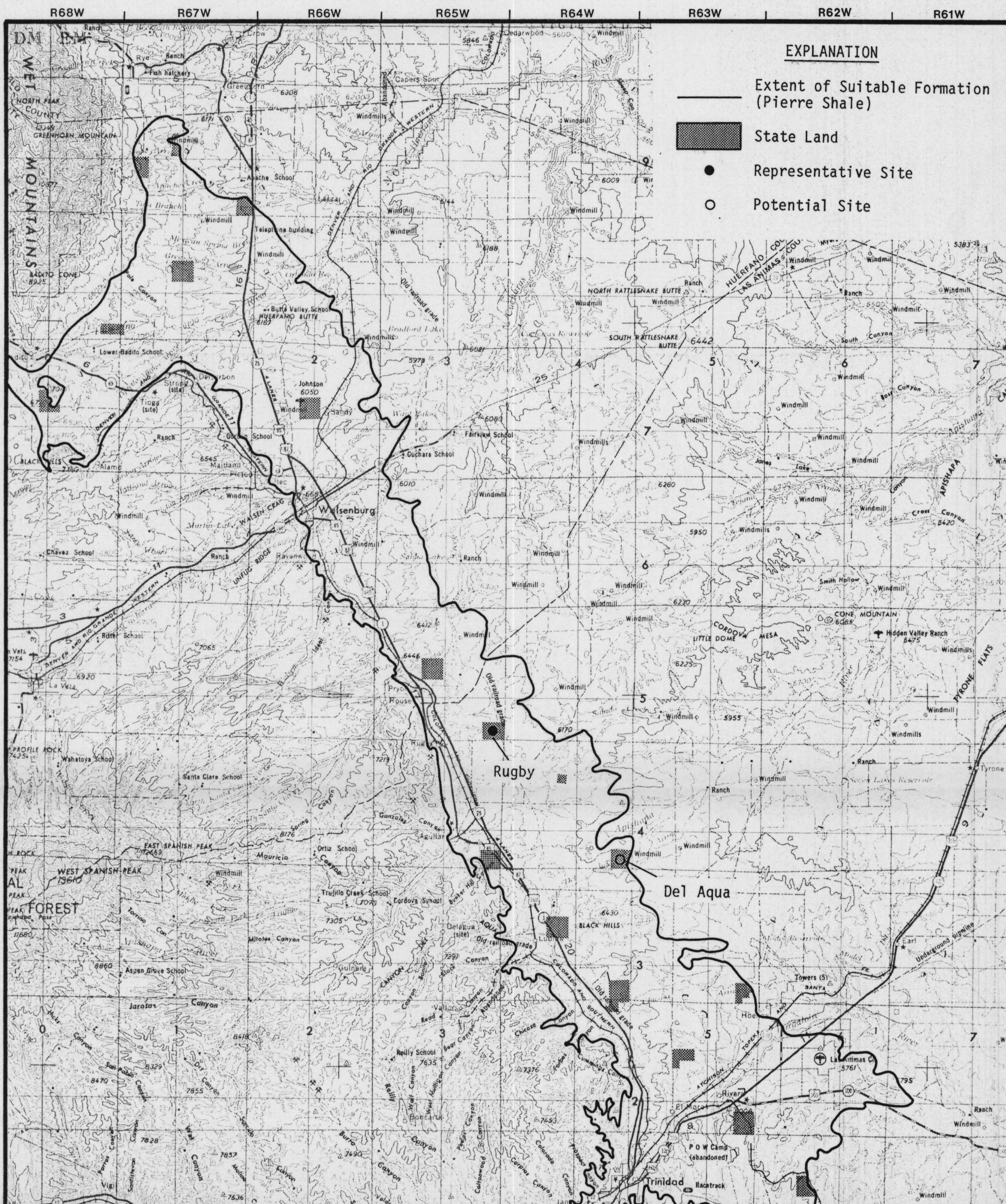

Figure 13. Location Map of the Southern Foothills Candidate Area, scale 1:300,000.

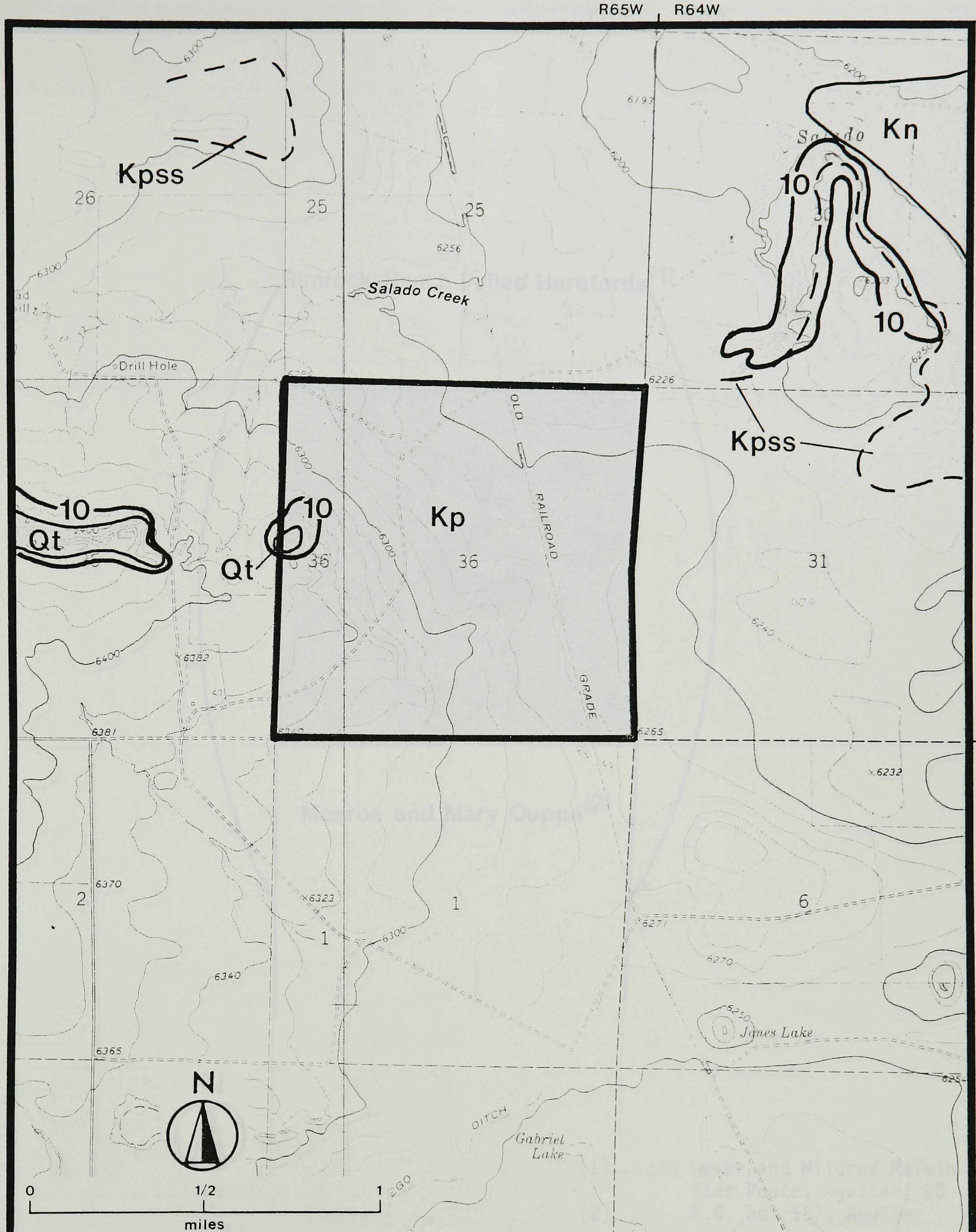

Figure 14. Surficial Geology and Slope Map of the Rugby Site, scale 1:24,000.

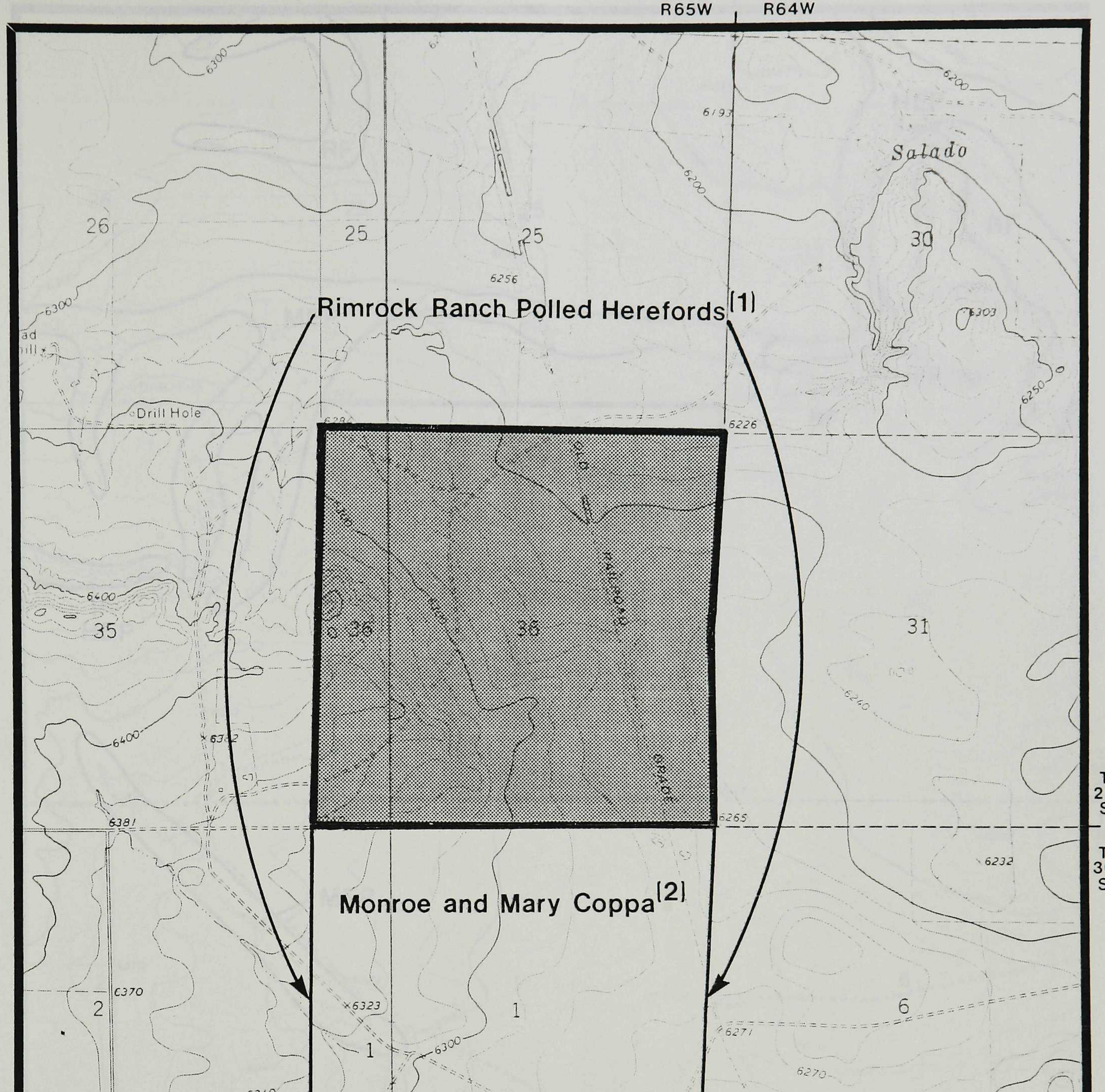

Figure 15. Land Ownership Map of the Rugby Site, scale 1:24,000.

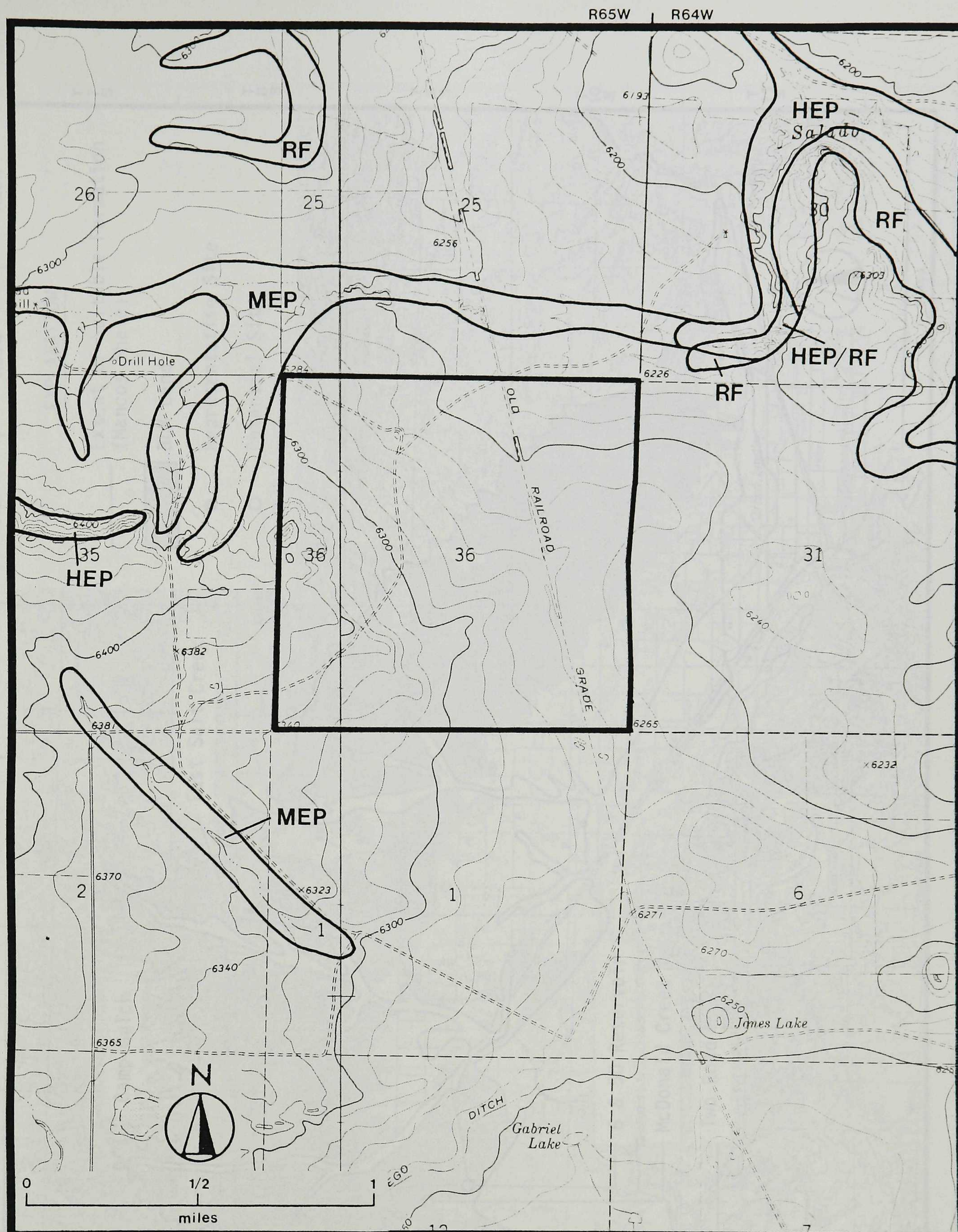

Figure 16. Geologic Hazards and Constraints Map of the Rugby Site, scale 1:24,000.

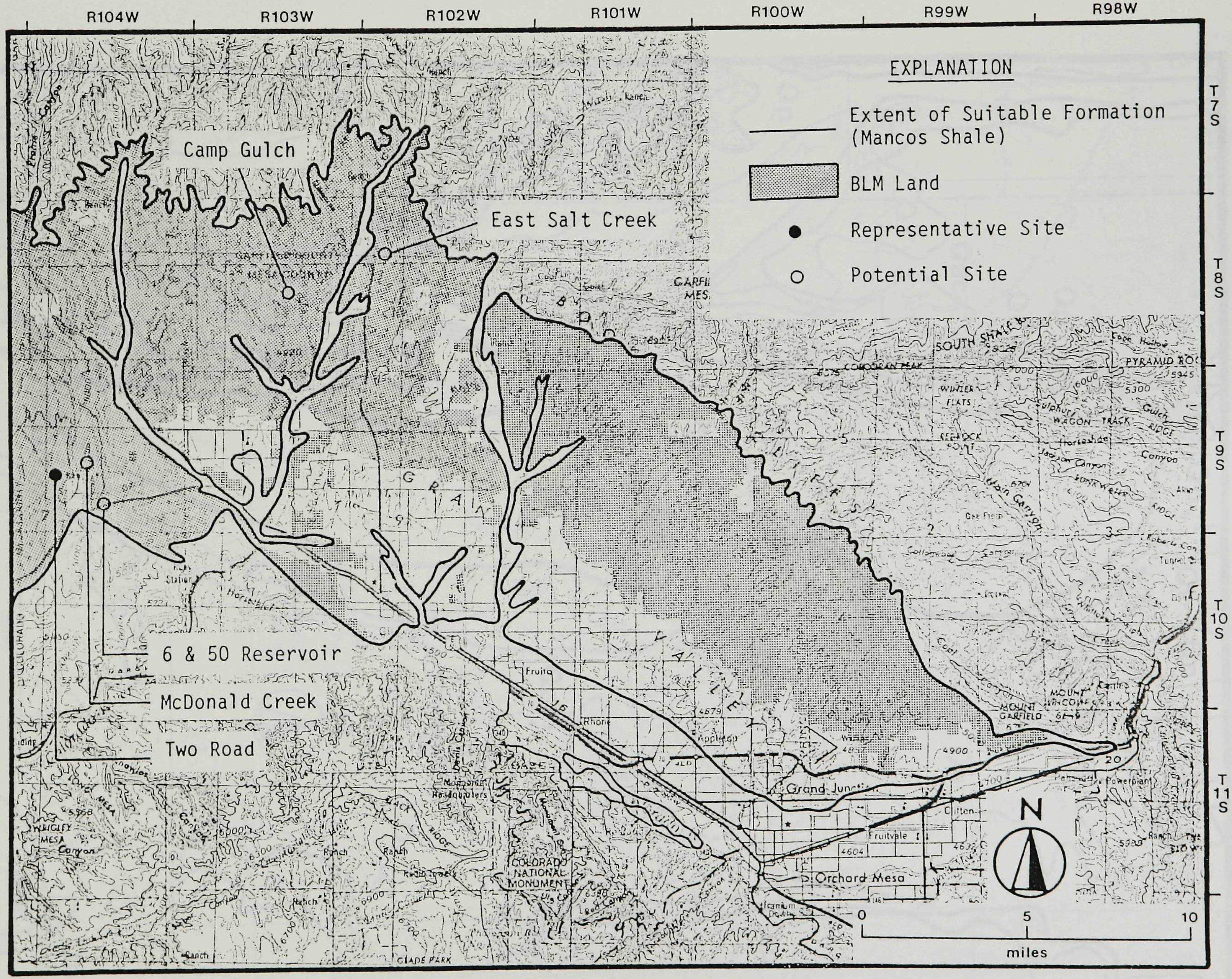

Figure 17. Location Map of the Grand Valley Candidate Area, scale 1:300,000.

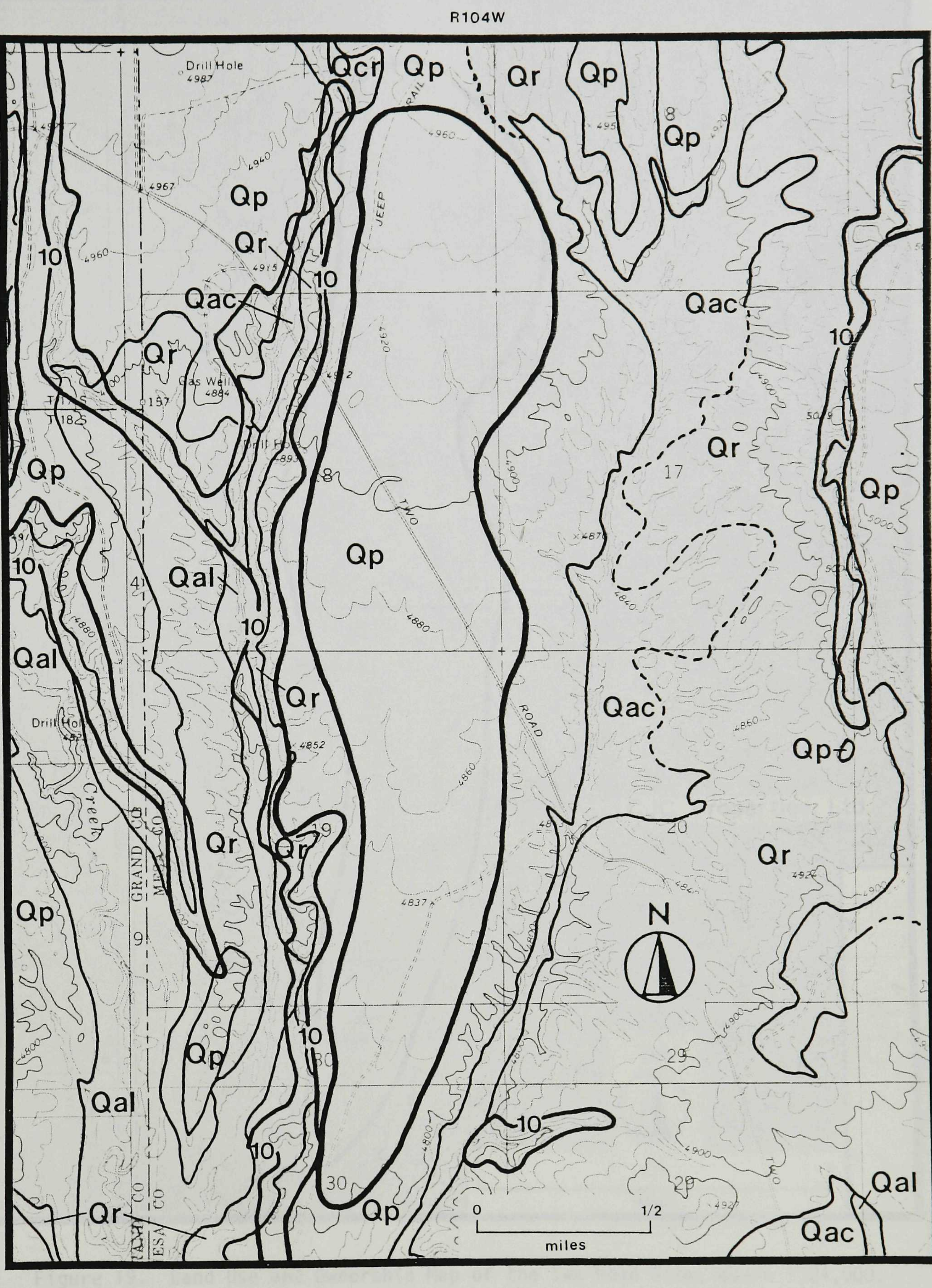

Figure 18. Surficial Geology and Slope Map of the Two Road Site, scale 1:24,000.

R104W

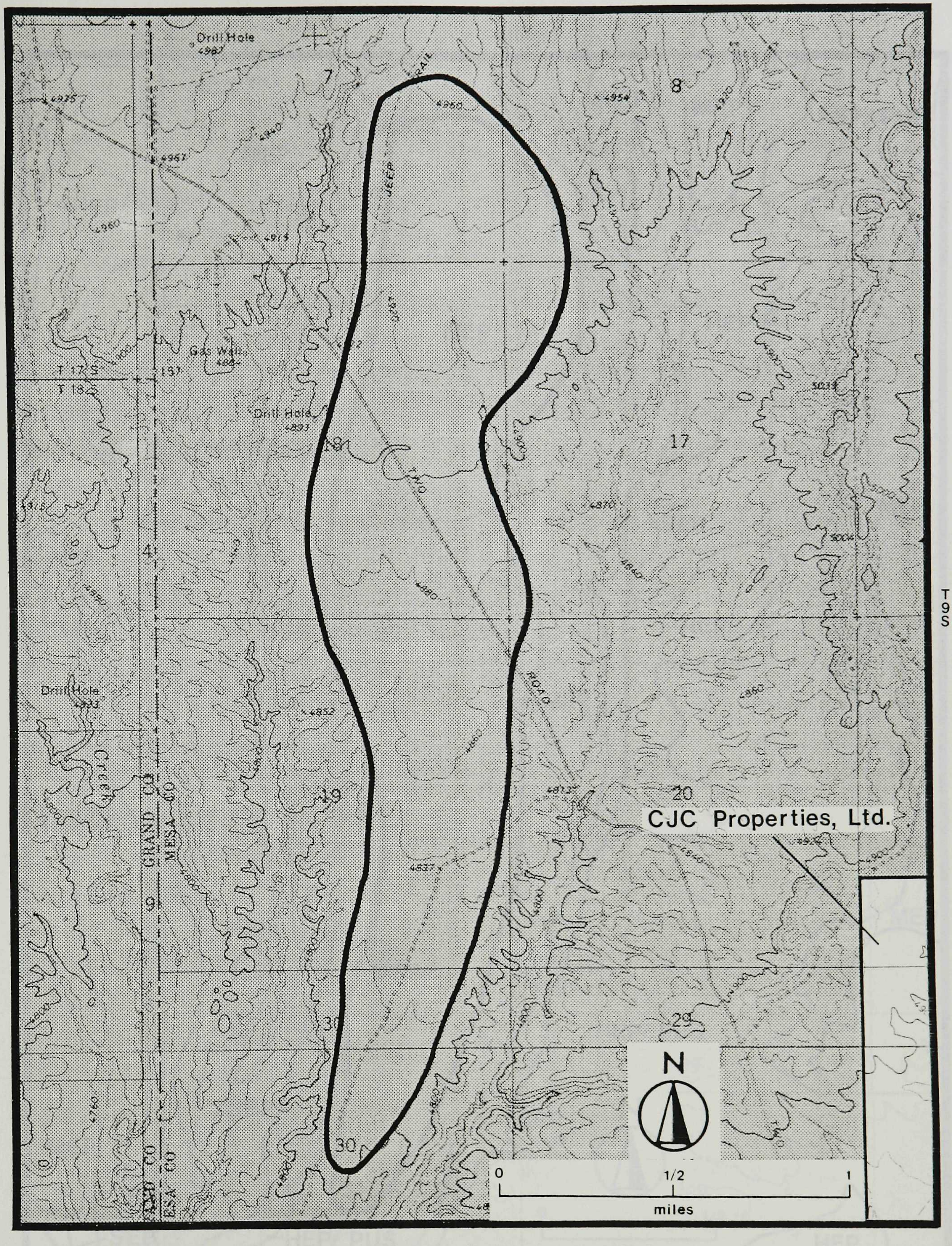

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Figure 19. Land Use and Ownership Map of the Two Road Site, scale 1:24,000.

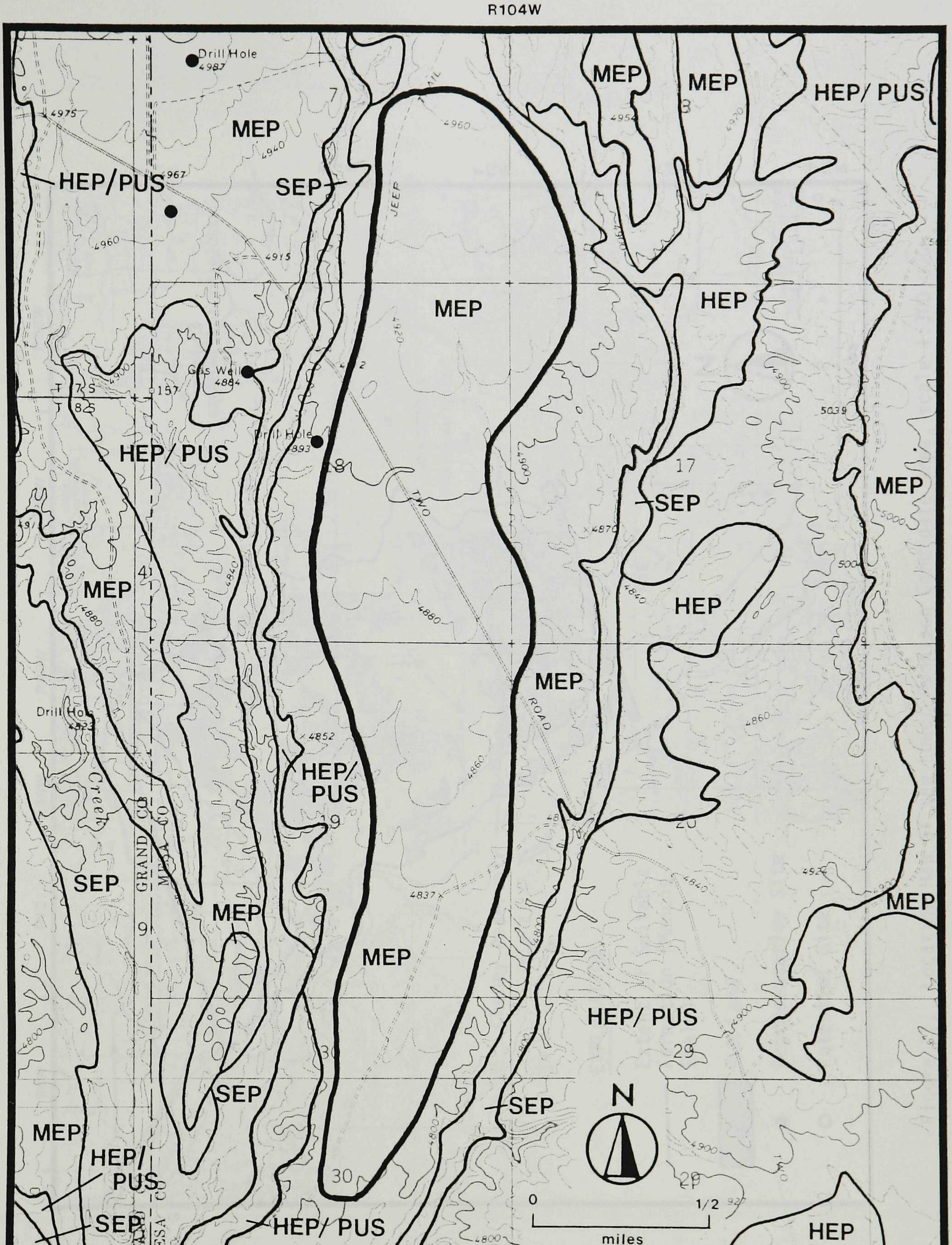

Figure 20. Geologic Hazards and Constraints Map of the Two Road Site, scale 1:24,000.

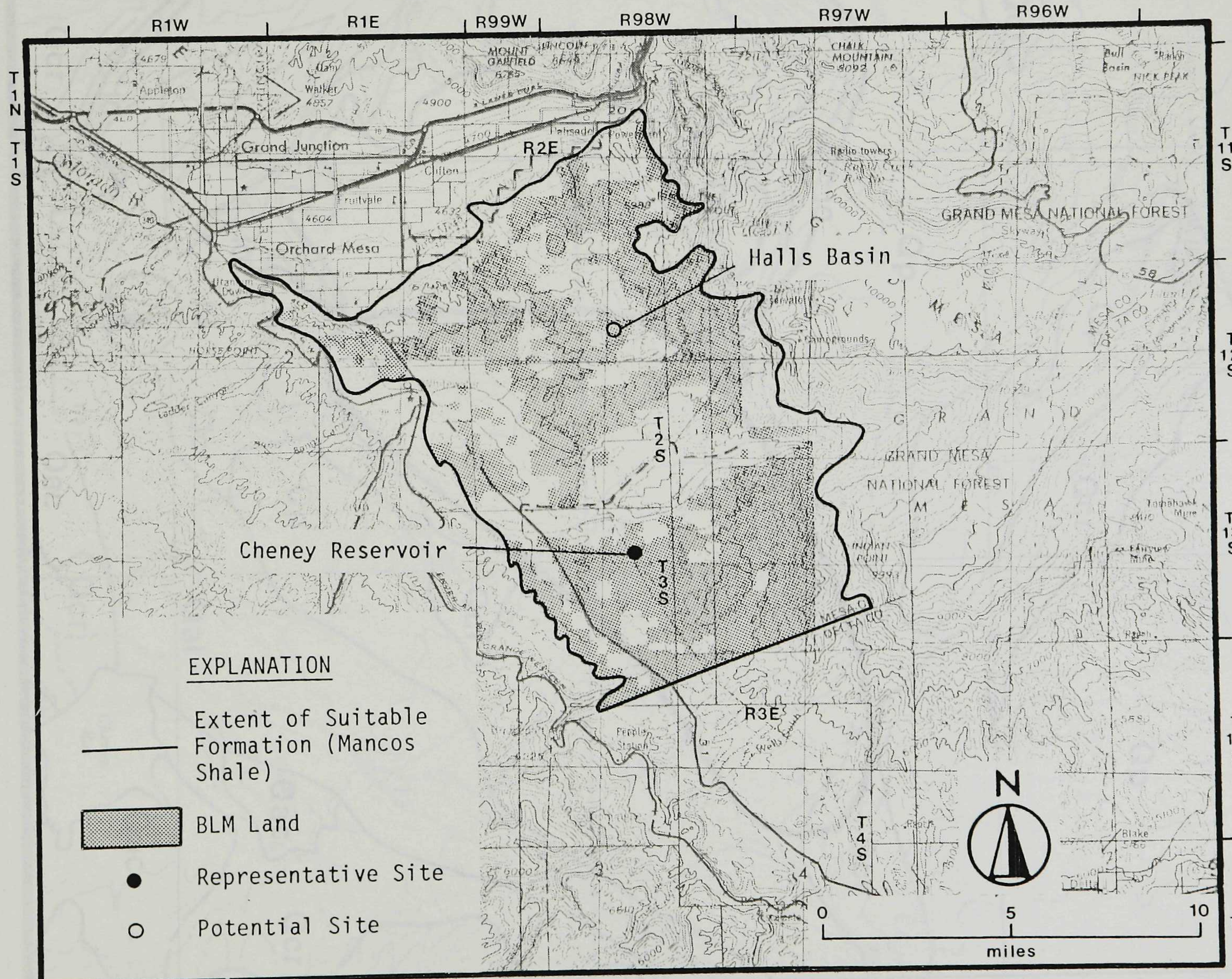

Figure 21. Location Map of the Lower Gunnison Candidate Area, scale 1:300,000.

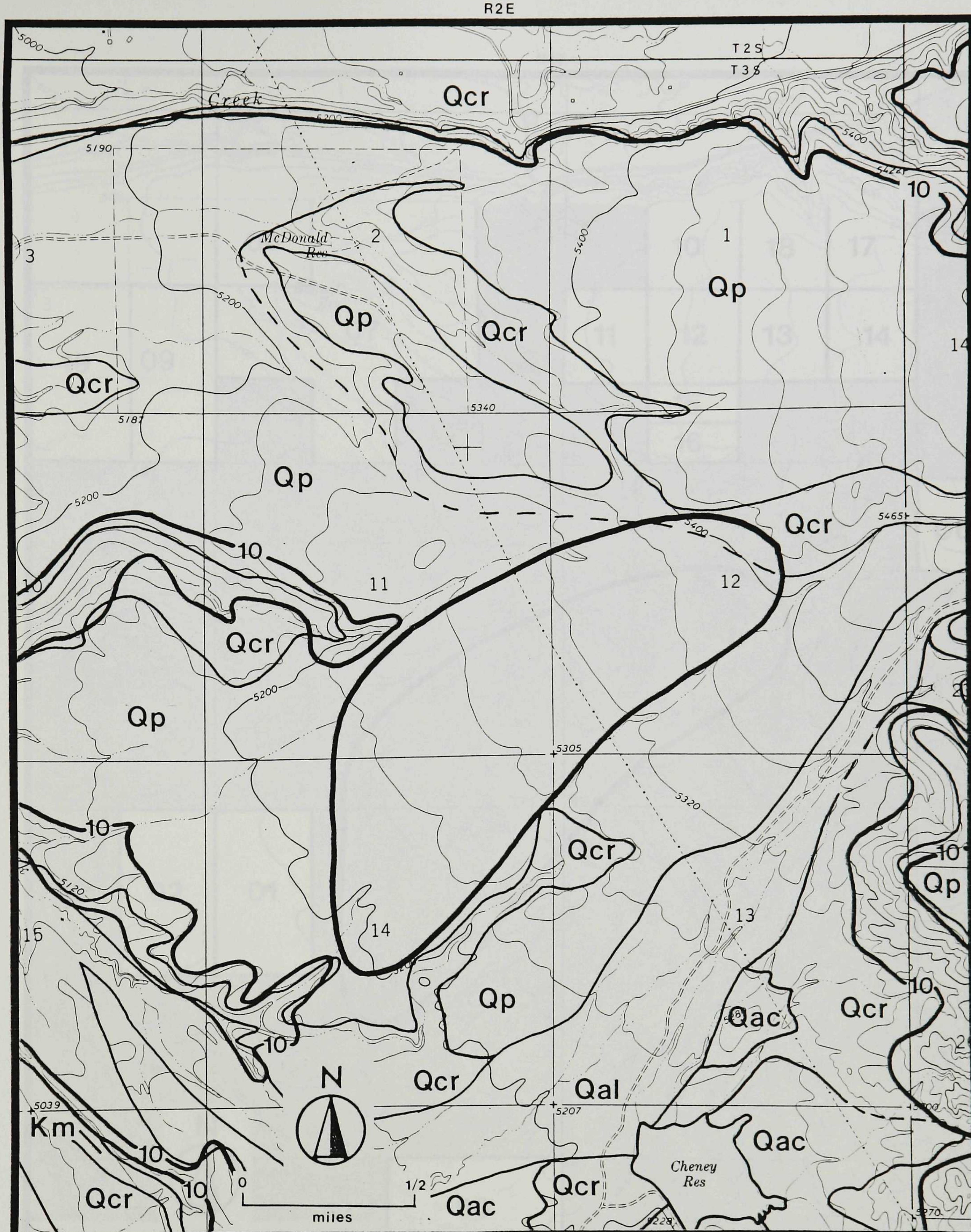

Figure 22. Surficial Geology and Slope Map of the Cheney Reservoir Site, scale 1:24,000.

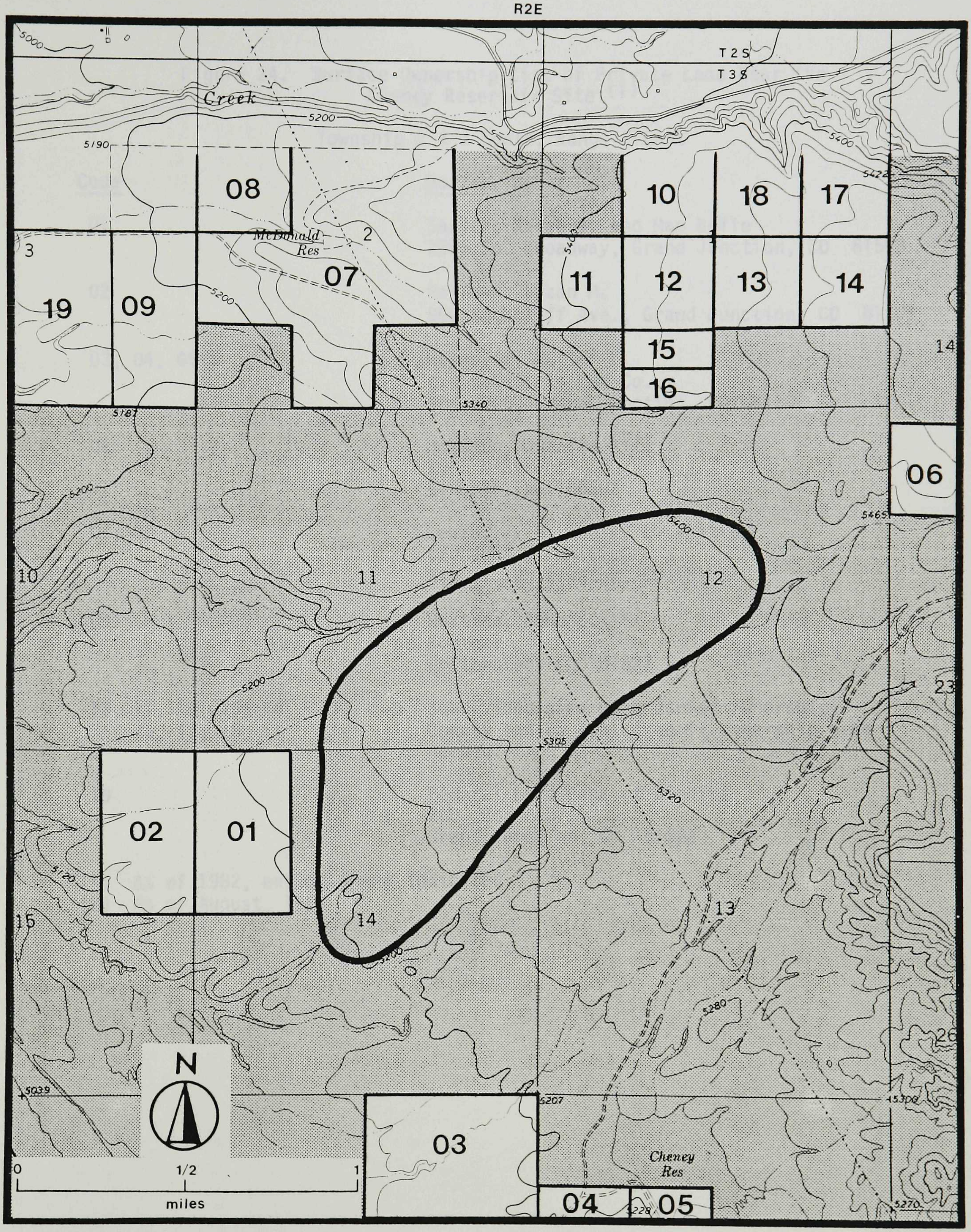

Figure 23. Land Use and Ownership Map of the Cheney Reservoir Site, scale 1:24,000.

Figure 24. Surface Ownership List of Private Land Near the Cheney Reservoir Site (1)

Township 2 & 3 South, Range 2 East

Code	Surface Owner
01	Sasser, Ralph J. and Mae Belle 2235 So. Broadway, Grand Junction, CO 81503
02	Hartman, Suzan M. 960 Bookcliff Ave., Grand Junction, CO 81501
03, 04, 05	Weymeyer, Walter K. c/o Wakefield MGN Co. Box 2206, Grand Junction, CO 81502
06	Johnson, Juanita (2) 1971 D Street Lincoln, NB 86502
07, 08	Lewis, J. B. and R. L. Whiting c/o John L. Whiting Rte. 1, Whitewater, CO 81527
09	Whiting, John L. (2) Route 1 Whitewater, CO 81527
10, 11, 12, 13, 14, 15, 16, 17, 18	Subdivided area with varied ownership; County can be contacted if ownership data needed.
19	Federal Land Bank of Wichita P.O. Box 1087 Grand Junction, CO 81502

(1) As of 1982, except where indicated
(2) As of August, 1986

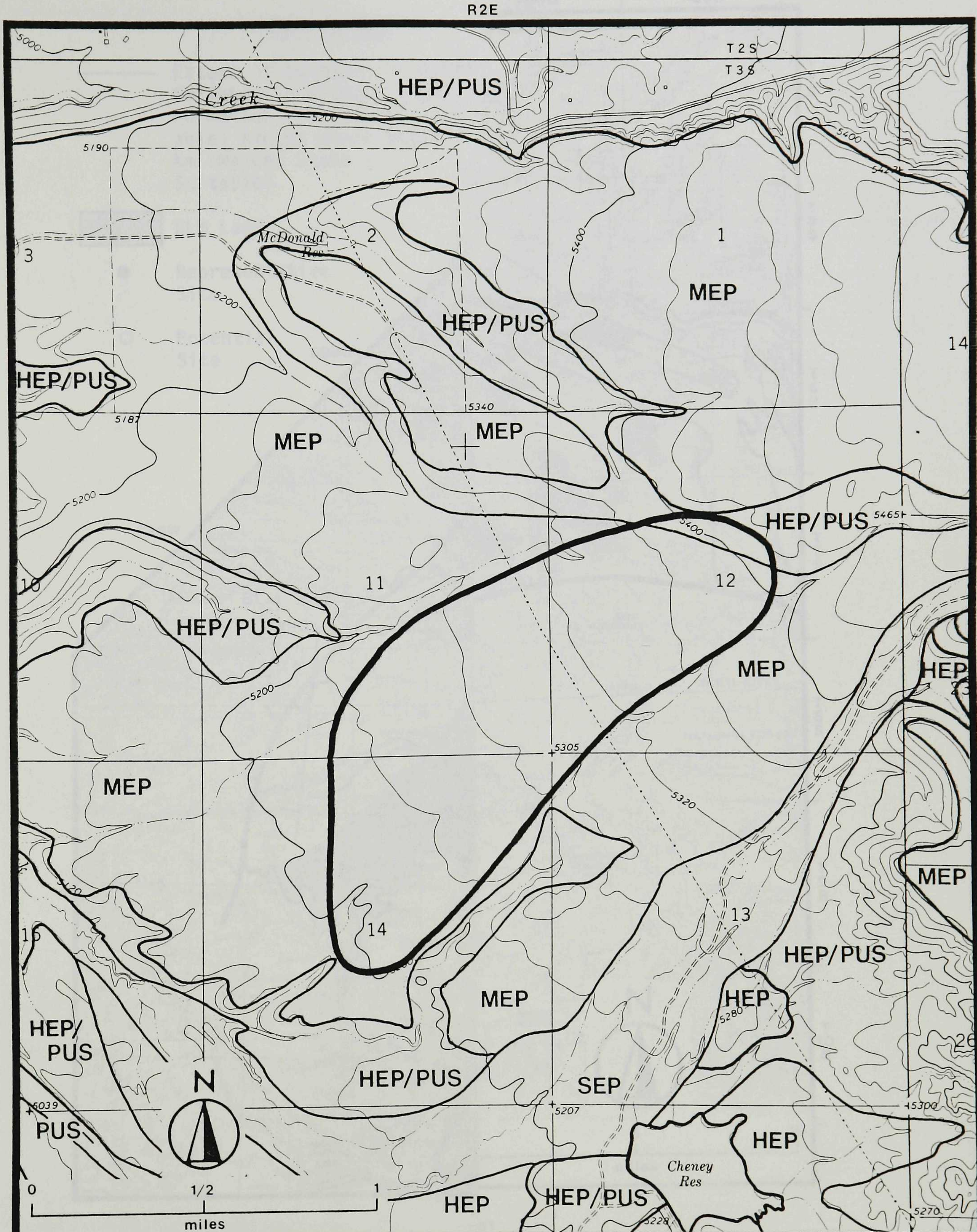

Figure 25. Geologic Hazards and Constraints Map of the Cheney Reservoir Site scale 1:24,000.

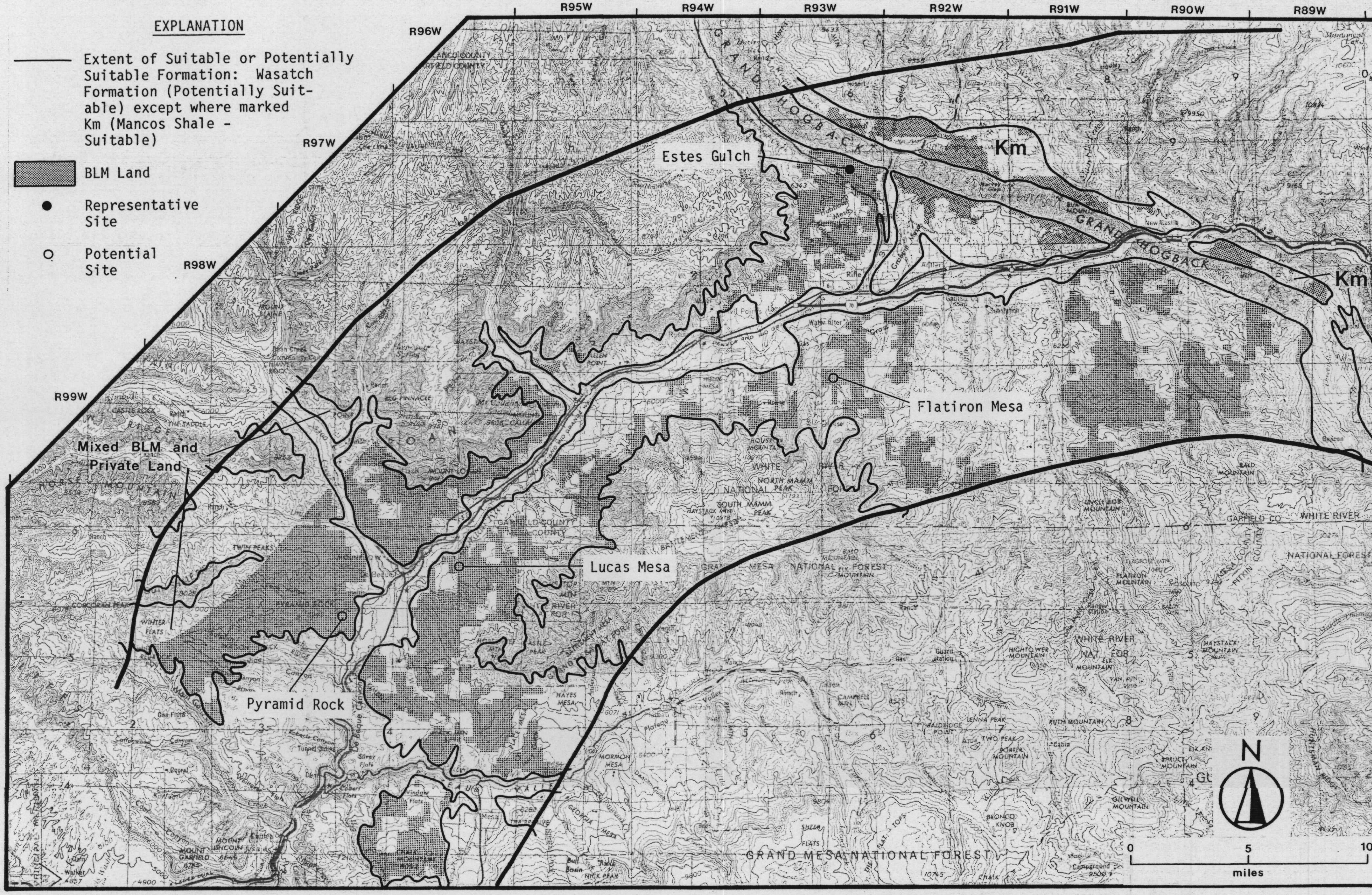

Figure 26. Location Map of the Grand Hogback Candidate Area, scale 1:300,000.

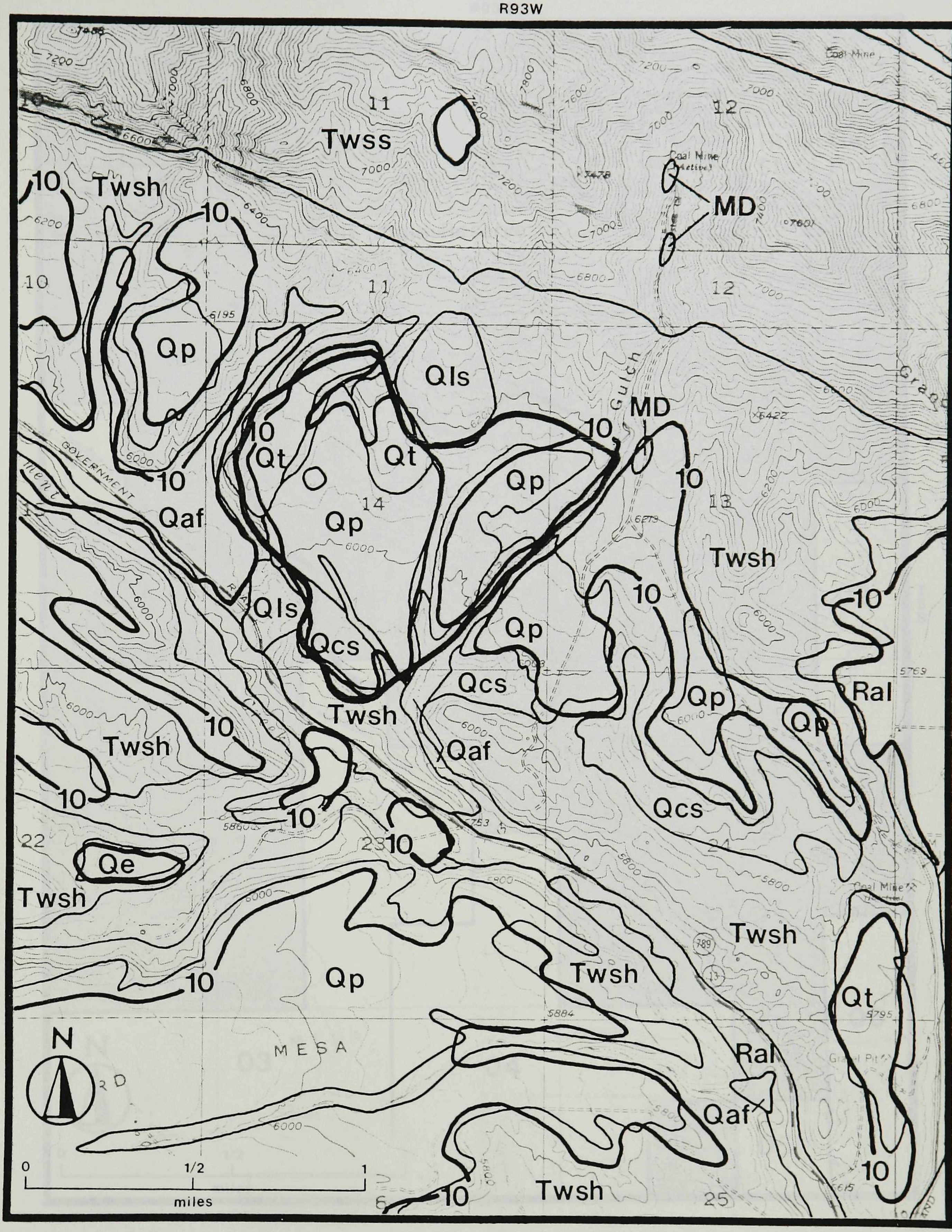

Figure 27. Surficial Geology and Slope Map of the Estes Gulch Site, scale 1:24,000.

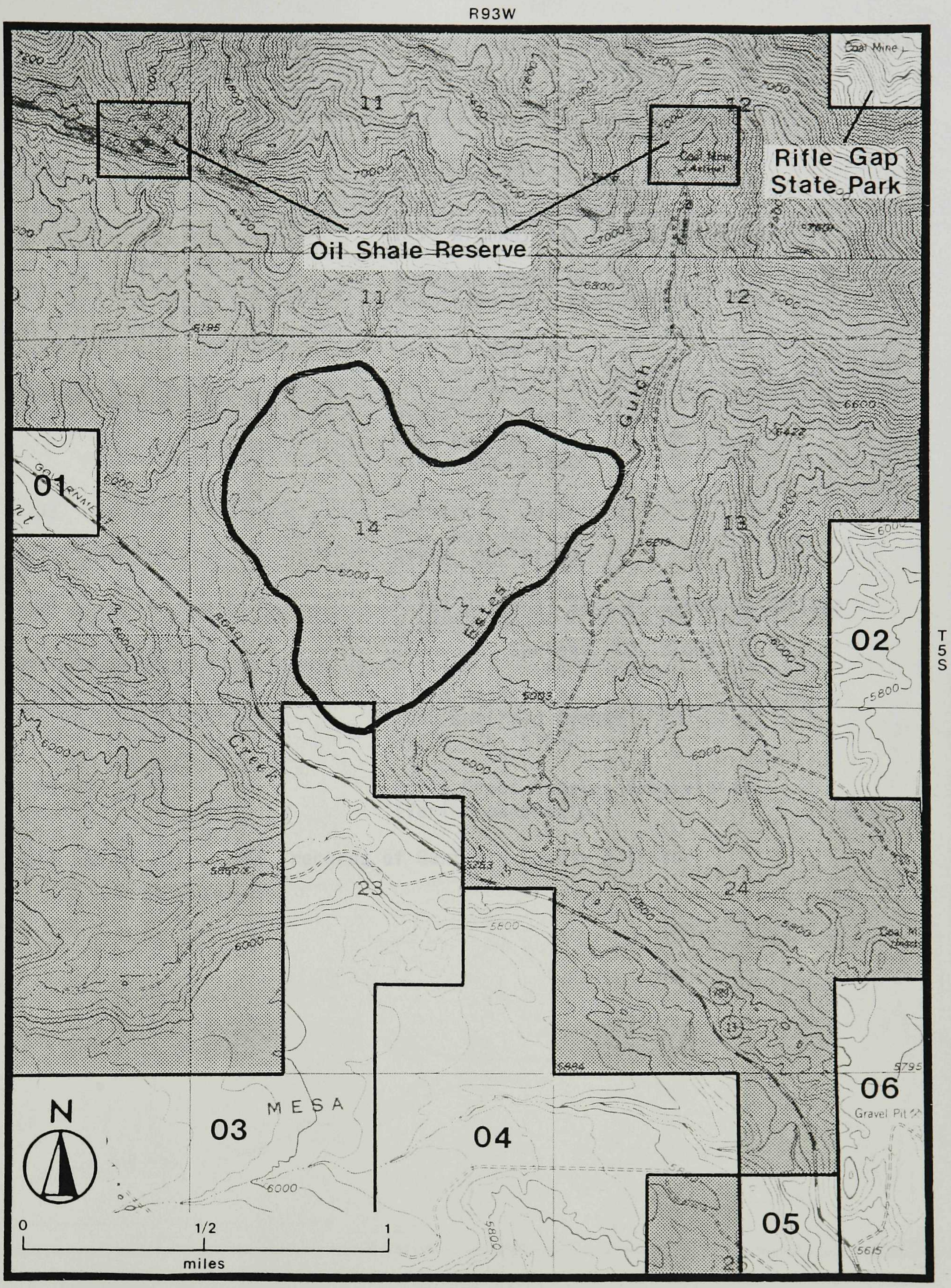

Figure 28. Land Use and Ownership Map of the Estes Gulch Site, scale 1:24,000.

Figure 29. Surface Ownership List of Private Land Near the Estes Gulch Site

Township 5 South, Range 93 West (1)

Code		Surface Owner
01	3 parcels:	John M. and Raymond R. Lyons, Jr. 7190 Highway 13, Rifle, CO 81650
		Kuchlers Water Wells 1560 6450 Rd., Montrose, CO 81401
		Gary W. Hausler 410 Central Ave., Apt. C, Alameda, CA 94501
02		Rifle Gap Land Co. P.O. Box 389 Rifle, CO 81650
03		Herbert L. Jolley P.O. Box 148 Rifle, CO 81650
04		First National Bank of Glenwood Springs P.O. Box 908 Glenwood, Springs, CO 81602
05		S & M Associates 1595 Railroad Avenue Rifle, CO 81650
06		Rifle Creek Estates Subdivision (Varied ownership)

(1) As of July, 1986, records of Garfield County Assessor

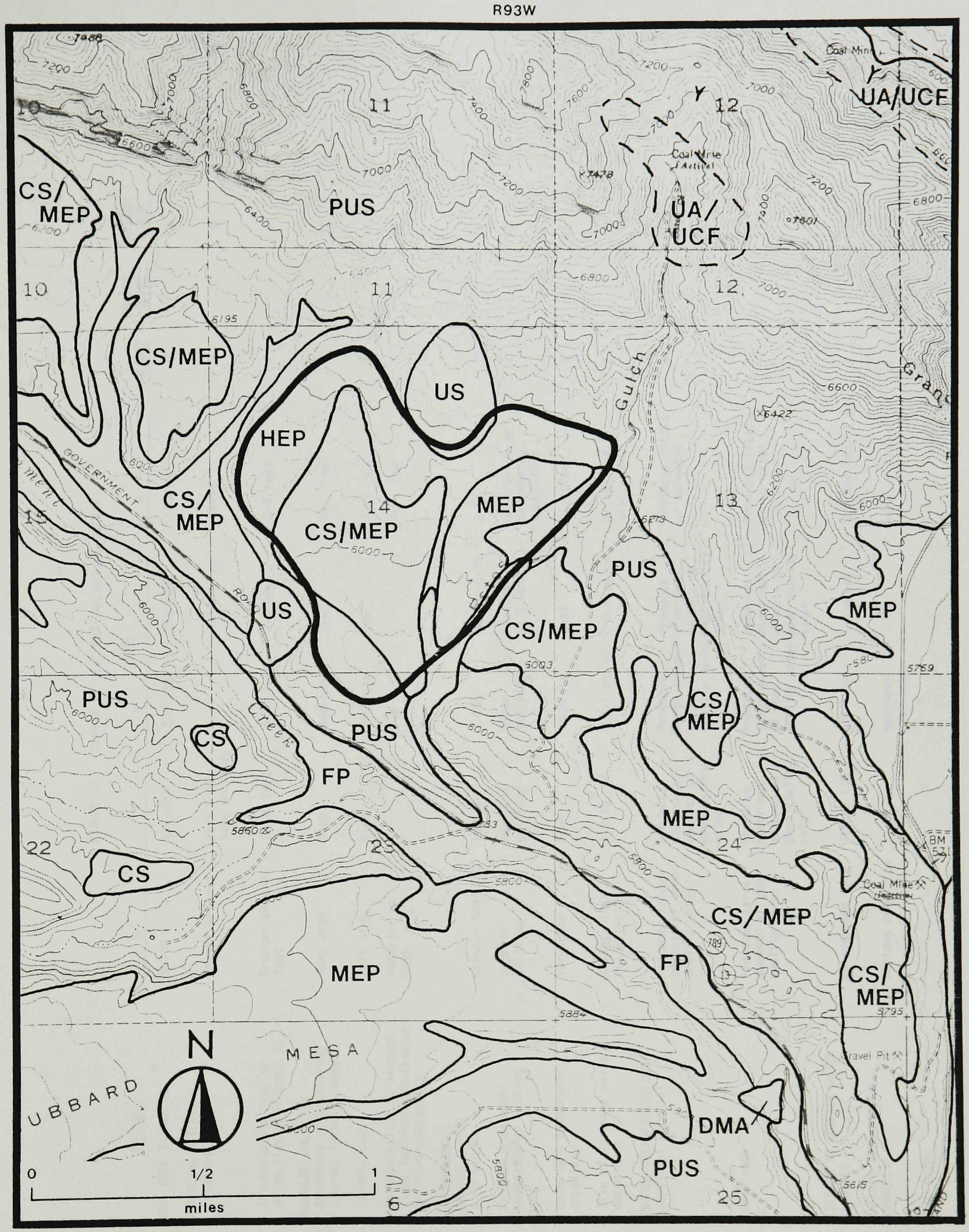

Figure 30. Geologic Hazards and Constraints Map of the Estes Gulch Site, scale 1:24,000.

FIGURE 31. EXAMPLE OF GEOTECHNICAL RATING MATRIX

FACTOR	RANK 0	1	2	3	4	WEIGHT	FACTOR SCORE	MAXIMUM SCORE
HOST ROCK THICKNESS	0-100'	100-200'	200-500'	500-1000'	1000'+	2		8
SURFICIAL MATERIALS								
Lithology	Gravel or sand	Very fine sand or sandy silt	Silt	Silty clay	Clay	2		8
Thickness (if clay or silty clay site ranks 4)	Greater than 20 feet	10-20 feet	5-10 feet	2-5 feet	0-2 feet	2		8
GEOLOGIC STABILITY								
Abundance of fracturing (joints & shear zones)	Very high	High	Moderate	Low	Very low	1		4
Seismic risk	Very high	High	Moderate	Low	Very low	1		4
Susceptibility to natural slope failures, subsidence or hydro-compaction	Moderate to high		Low		Very low	3		12
GEOMORPHOLOGIC CHARACTERISTICS								
Land Slope	Greater than 15%	10-15%	7-10%	0-2 or 5-7%	2-5%	1		4
Present erosional/ depositional setting	Intense gullying	Moderate gullying	Minor gullying	Sheet or rill wash	No erosion or undergoing deposition	3		12
Long-term geomorphic stability	Very poor	Poor	Moderate	Good	Excellent	3		12
Size of drainage basin above site	Greater than 2 sq. miles	1-2 sq. mi.	0.5-1 sq. mi.	0-0.5 sq. mi.	At head of drainage	2		8
AQUIFER CHARACTERISTICS								
Surficial material	Produces large amounts of good quality water	Produces minor-mod. amounts of good quality water	Produces large amounts of poor quality water	Produces minor-mod. amounts of poor quality water	Produces little or no water	3		12
Host rock	Produces large amounts of good quality water	Produces minor-mod. amounts of good quality water	Produces large amounts of poor quality water	Produces minor-mod. amounts of poor quality water	Produces little or no water	3		12
DISTANCE TO SURFACE WATER RESOURCES	On proposed site	Within 1/2 mi.	1/2-1 mile	1-2 miles	Greater than 2 mi.	3		12
CONFLICT WITH MINERAL RESOURCES	Serious conflicts		Moderate conflicts		None or minor	1		4
TOTAL SCORE								120

TABLE 1. GEOTECHNICAL RATING MATRIX FOR THE TWO ROAD SITE

FACTOR	RANK 0	1	2	3	4	WEIGHT	FACTOR SCORE
HOST ROCK THICKNESS	0-100'	100-200'	200-500'	500-1000'	1000'+	2	6
SURFICIAL MATERIALS Lithology	Gravel or sand	Very fine sand or sandy silt	Silt	Silty clay	Clay	2	6
Thickness (if clay or silty clay site ranks 4)	Greater than 20 feet	10-20 feet	5-10 feet	2-5 feet	0-2 feet	2	8
GEOLOGIC STABILITY Abundance of fracturing (joints & shear zones)	Very high	High	Moderate	Low	Very low	1	4
Seismic risk	Very high	High	Moderate	Low	Very low	1	2
Susceptibility to natural slope failures, subsidence, or hydro-compaction	Moderate to high		Low		Very low	3	12
GEOMORPHOLOGIC CHARACTERISTICS Land Slope	Greater than 15%	10-15%	7-10%	0-2 or 5-7%	2-5%	1	4
Present erosional/ depositional setting	Intense gullying	Moderate gullying	Minor gullying	Sheet or rill wash	No erosion or undergoing deposition	3	9
Long-term geomorphic stability	Very poor	Poor	Moderate	Good	Excellent	3	12
Size of drainage basin above site	Greater than 2 sq. miles	1-2 sq. mi.	0.5-1 sq. mi.	0-0.5 sq. mi.	At head of drainage	2	8
AQUIFER CHARACTERISTICS Surficial material	Produces large amounts of good quality water	Produces minor-mod. amounts of good quality water	Produces large amounts of poor quality water	Produces minor-mod. amounts of poor quality water	Produces little or no water	3	12
Host rock	Produces large amounts of good quality water	Produces minor-mod. amounts of good quality water	Produces large amounts of poor quality water	Produces minor-mod. amounts of poor quality water	Produces little or no water	3	12
DISTANCE TO SURFACE WATER RESOURCES	On proposed site	Within 1/2 mi.	1/2-1 mile	1-2 miles	Greater than 2 mi.	3	12
CONFLICT WITH MINERAL RESOURCES	Serious conflicts		Moderate conflicts		None or minor	1	2
TOTAL SCORE							109

TABLE 2. GEOTECHNICAL RATING MATRIX FOR THE CLIFFORD SITE

FACTOR	RANK 0	1	2	3	4	WEIGHT	FACTOR SCORE
HOST ROCK THICKNESS	0-100'	100-200'	200-500'	500-1000'	1000'+	2	8
SURFICIAL MATERIALS							
Lithology	Gravel or sand	Very fine sand or sandy silt	Silt	Silty clay	Clay	2	8
Thickness (if clay or silty clay site ranks 4)	Greater than 20 feet	10-20 feet	5-10 feet	2-5 feet	0-2 feet	2	8
GEOLOGIC STABILITY							
Abundance of fracturing (joints & shear zones)	Very high	High	Moderate	Low	Very low	1	3
Seismic risk	Very high	High	Moderate	Low	Very low	1	4
Susceptibility to natural slope failures, subsidence, or hydro-compaction	Moderate to high		Low		Very low	3	12
GEOMORPHOLOGIC CHARACTERISTICS							
Land Slope	Greater than 15%	10-15%	7-10%	0-2 or 5-7%	2-5%	1	3
Present erosional/ depositional setting	Intense gullying	Moderate gullying	Minor gullying	Sheet or rill wash	No erosion or undergoing deposition	3	9
Long-term geomorphic stability	Very poor	Poor	Moderate	Good	Excellent	3	12
Size of drainage basin above site	Greater than 2 sq. miles	1-2 sq. mi.	0.5-1 sq. mi.	0-0.5 sq. mi.	At head of drainage	2	6
AQUIFER CHARACTERISTICS							
Surficial material	Produces large amounts of good quality water	Produces minor-mod. amounts of good quality water	Produces large amounts of poor quality water	Produces minor-mod. amounts of poor quality water	Produces little or no water	3	9
Host rock	Produces large amounts of good quality water	Produces minor-mod. amounts of good quality water	Produces large amounts of poor quality water	Produces minor-mod. amounts of poor quality water	Produces little or no water	3	12
DISTANCE TO SURFACE WATER RESOURCES	On proposed site	Within 1/2 mi.	1/2-1 mile	1-2 miles	Greater than 2 mi.	3	12
CONFLICT WITH MINERAL RESOURCES	Serious conflicts		Moderate conflicts		None or minor	1	2
TOTAL SCORE							108

TABLE 3. GEOTECHNICAL RATING MATRIX FOR THE WIGWAM SITE

FACTOR	RANK 0	1	2	3	4	WEIGHT	FACTOR SCORE
HOST ROCK THICKNESS	0-100'	100-200'	200-500'	500-1000'	1000'+	2	8
SURFICIAL MATERIALS							
Lithology	Gravel or sand	Very fine sand or sandy silt	Silt	Silty clay	Clay	2	8
Thickness (if clay or silty clay site ranks 4)	Greater than 20 feet	10-20 feet	5-10 feet	2-5 feet	0-2 feet	2	8
GEOLOGIC STABILITY							
Abundance of fracturing (joints & shear zones)	Very high	High	Moderate	Low	Very low	1	3
Seismic risk	Very high	High	Moderate	Low	Very low	1	3
Susceptibility to natural slope failures, subsidence, or hydro-compaction	Moderate to high		Low		Very low	3	12
GEOMORPHOLOGIC CHARACTERISTICS							
Land Slope	Greater than 15%	10-15%	7-10%	0-2 or 5-7%	2-5%	1	3
Present erosional/depositional setting	Intense gullying	Moderate gullying	Minor gullying	Sheet or rill wash	No erosion or undergoing deposition	3	6
Long-term geomorphic stability	Very poor	Poor	Moderate	Good	Excellent	3	9
Size of drainage basin above site	Greater than 2 sq. miles	1-2 sq. mi.	0.5-1 sq. mi.	0-0.5 sq. mi.	At head of drainage	2	8
AQUIFER CHARACTERISTICS							
Surficial material	Produces large amounts of good quality water	Produces minor-mod. amounts of good quality water	Produces large amounts of poor quality water	Produces minor-mod. amounts of poor quality water	Produces little or no water	3	12
Host rock	Produces large amounts of good quality water	Produces minor-mod. amounts of good quality water	Produces large amounts of poor quality water	Produces minor-mod. amounts of poor quality water	Produces little or no water	3	12
DISTANCE TO SURFACE WATER RESOURCES	On proposed site	Within 1/2 mi.	1/2-1 mile	1-2 miles	Greater than 2 mi.	3	12
CONFLICT WITH MINERAL RESOURCES	Serious conflicts		Moderate conflicts		None or minor	1	4
TOTAL SCORE							108

TABLE 4. GEOTECHNICAL RATING MATRIX FOR THE RUGBY SITE

FACTOR	RANK 0	1	2	3	4	WEIGHT	FACTOR SCORE
HOST ROCK THICKNESS	0-100'	100-200'	200-500'	500-1000'	1000'+	2	8
SURFICIAL MATERIALS							
Lithology	Gravel or sand	Very fine sand or sandy silt	Silt	Silty clay	Clay	2	6
Thickness (if clay or silty clay site ranks 4)	Greater than 20 feet	10-20 feet	5-10 feet	2-5 feet	0-2 feet	2	8
GEOLOGIC STABILITY							
Abundance of fracturing (joints & shear zones)	Very high	High	Moderate	Low	Very low	1	3
Seismic risk	Very high	High	Moderate	Low	Very low	1	2
Susceptibility to natural slope failures, subsidence, or hydro-compaction	Moderate to high		Low		Very low	3	12
GEOMORPHOLOGIC CHARACTERISTICS							
Land Slope	Greater than 15%	10-15%	7-10%	0-2 or 5-7%	2-5%	1	3
Present erosional/ depositional setting	Intense gullying	Moderate gullying	Minor gullying	Sheet or rill wash	No erosion or undergoing deposition	3	9
Long-term geomorphic stability	Very poor	Poor	Moderate	Good	Excellent	3	12
Size of drainage basin above site	Greater than 2 sq. miles	1-2 sq. mi.	0.5-1 sq. mi.	0-0.5 sq. mi.	At head of drainage	2	8
AQUIFER CHARACTERISTICS							
Surficial material	Produces large amounts of good quality water	Produces minor-mod. amounts of good quality water	Produces large amounts of poor quality water	Produces minor-mod. amounts of poor quality water	Produces little or no water	3	12
Host rock	Produces large amounts of good quality water	Produces minor-mod. amounts of good quality water	Produces large amounts of poor quality water	Produces minor-mod. amounts of poor quality water	Produces little or no water	3	12
DISTANCE TO SURFACE WATER RESOURCES	On proposed site	Within 1/2 mi.	1/2-1 mile	1-2 miles	Greater than 2 mi.	3	6
CONFLICT WITH MINERAL RESOURCES	Serious conflicts		Moderate conflicts		None or minor	1	4
TOTAL SCORE							105

TABLE 5. GEOTECHNICAL RATING MATRIX FOR THE ESTES GULCH SITE

FACTOR	RANK 0	1	2	3	4	WEIGHT	FACTOR SCORE
HOST ROCK THICKNESS	0-100'	100-200'	200-500'	500-1000'	1000'+	2	4
SURFICIAL MATERIALS							
Lithology	Gravel or sand	Very fine sand or sandy silt	Silt	Silty clay	Clay	2	6
Thickness (if clay or silty clay site ranks 4)	Greater than 20 feet	10-20 feet	5-10 feet	2-5 feet	0-2 feet	2	8
GEOLOGIC STABILITY							
Abundance of fracturing (joints & shear zones)	Very high	High	Moderate	Low	Very low	1	2
Seismic risk	Very high	High	Moderate	Low	Very low	1	2
Susceptibility to natural slope failures, subsidence or hydro-compaction	Moderate to high		Low		Very low	3	12
GEOMORPHOLOGIC CHARACTERISTICS							
Land Slope	Greater than 15%	10-15%	7-10%	0-2 or 5-7%	2-5%	1	3
Present erosional/ depositional setting	Intense gullying	Moderate gullying	Minor gullying	Sheet or rill wash	No erosion or undergoing deposition	3	6
Long-term geomorphic stability	Very poor	Poor	Moderate	Good	Excellent	3	9
Size of drainage basin above site	Greater than 2 sq. miles	1-2 sq. mi.	0.5-1 sq. mi.	0-0.5 sq. mi.	At head of drainage	2	8
AQUIFER CHARACTERISTICS							
Surficial material	Produces large amounts of good quality water	Produces minor-mod. amounts of good quality water	Produces large amounts of poor quality water	Produces minor-mod. amounts of poor quality water	Produces little or no water	3	12
Host rock	Produces large amounts of good quality water	Produces minor-mod. amounts of good quality water	Produces large amounts of poor quality water	Produces minor-mod. amounts of poor quality water	Produces little or no water	3	12
DISTANCE TO SURFACE WATER RESOURCES	On proposed site	Within 1/2 mi.	1/2-1 mile	1-2 miles	Greater than 2 mi.	3	6
CONFLICT WITH MINERAL RESOURCES	Serious conflicts		Moderate conflicts		None or minor	1	4
TOTAL SCORE							94

TABLE 6. GEOTECHNICAL RATING MATRIX FOR THE CHENEY RESERVOIR SITE

FACTOR	RANK 0	1	2	3	4	WEIGHT	FACTOR SCORE
HOST ROCK THICKNESS	0-100'	100-200'	200-500'	500-1000'	1000'+	2	4
SURFICIAL MATERIALS							
Lithology	Gravel or sand	Very fine sand or sandy silt	Silt	Silty clay	Clay	2	0
Thickness (if clay or silty clay site ranks 4)	Greater than 20 feet	10-20 feet	5-10 feet	2-5 feet	0-2 feet	2	0
GEOLOGIC STABILITY							
Abundance of fracturing (joints & shear zones)	Very high	High	Moderate	Low	Very low	1	4
Seismic risk	Very high	High	Moderate	Low	Very low	1	2
Susceptibility to natural slope failures, subsidence or hydro-compaction	Moderate to high		Low		Very low	3	12
GEOMORPHOLOGIC CHARACTERISTICS							
Land Slope	Greater than 15%	10-15%	7-10%	0-2 or 5-7%	2-5%	1	4
Present erosional/ depositional setting	Intense gullying	Moderate gullying	Minor gullying	Sheet or rill wash	No erosion or undergoing deposition	3	9
Long-term geomorphic stability	Very poor	Poor	Moderate	Good	Excellent	3	12
Size of drainage basin above site	Greater than 2 sq. miles	1-2 sq. mi.	0.5-1 sq. mi.	0-0.5 sq. mi.	At head of drainage	2	6
AQUIFER CHARACTERISTICS							
Surficial material	Produces large amounts of good quality water	Produces minor-mod. amounts of good quality water	Produces large amounts of poor quality water	Produces minor-mod. amounts of poor quality water	Produces little or no water	3	9
Host rock	Produces large amounts of good quality water	Produces minor-mod. amounts of good quality water	Produces large amounts of poor quality water	Produces minor-mod. amounts of poor quality water	Produces little or no water	3	12
DISTANCE TO SURFACE WATER RESOURCES	On proposed site	Within 1/2 mi.	1/2-1 mile	1-2 miles	Greater than 2 mi.	3	6
CONFLICT WITH MINERAL RESOURCES	Serious conflicts		Moderate conflicts		None or minor	1	4
TOTAL SCORE							84

APPENDIX

PERFORMANCE OBJECTIVES AND TECHNICAL CRITERIA
LOW LEVEL RADIOACTIVE WASTE DISPOSAL

April 16, 1985

State of Colorado

INTRODUCTION

Land disposal facilities must be sited, monitored, designed, constructed, operated, and closed so exposures to humans are within the limits established in Colorado's Rules and Regulations Pertaining to Radiation Control (24-11-101 et. seq. CRS 1982). To assure that these rules and regulations are met, performance objectives and technical criteria have been developed specifically for land disposal of low-level radioactive wastes. These performance objectives and technical criteria for land disposal facilities must be followed closely. Applications for land disposal of low-level radioactive waste must clearly demonstrate that the performance objectives and technical criteria will be met and that potential contaminant releases are as low as reasonably achievable.

PERFORMANCE OBJECTIVES

Objective 1 -- Protection of the general population from releases of radioactivity.

Concentrations of radioactive material which may be released to the general environment in ground water, surface water, air, soil, plants, and animals must not result in an annual dose exceeding an equivalent of 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public. Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable.

Objective 2 -- Suitability of the disposal site

In the selection of disposal sites, primary emphasis shall be given to isolation of the waste materials and associated contaminants from humans and the environment for the short term and for the long term without ongoing active maintenance. Long-term isolation shall include the control of radionuclides and non-radioactive contaminants, for thousands of years. While isolation of the waste will be a function of site characteristics, engineering design, and prudent operation, overriding consideration shall be given to optimal siting features.

Objective 3 -- Protection of individuals during operations.

Operations at the land disposal facility must be conducted in compliance with the standards for radiation protection set out in Colorado's "Rules and Regulations Pertaining to Radiation Control" and shall be governed by Objectives 1 and 2. Every reasonable effort shall be made to maintain radiation exposures as low as is reasonably achievable.

Objective 4 -- Protection of individuals from inadvertent intrusion.

Design, operation, and closure of the land disposal facility must ensure protection of any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste at any time after active institutional controls over the disposal site are removed.

Objective 5 -- Stability of the disposal site after closure.

The disposal facility must be sited, designed, constructed, operated, and closed to achieve long-term stability of the disposal site and to eliminate the need for ongoing active maintenance of the disposal site following closure. Only surveillance, monitoring, or minor custodial care should be required. Long-term stability of the site shall include minimizing erosion, disturbance, and dispersion by natural forces, continued immobilization and isolation of contaminants from surface and ground waters, and control of surface exhalation of radioactive gases.

TECHNICAL CRITERIA

The following criteria establish the basic requirements for meeting the performance objectives. In general, these criteria encompass all aspects of low level waste disposal including siting, design, construction, operation, closure, and monitoring. These activities are interrelated and non-performance of one aspect could influence or adversely impact other project activities. To ensure that all aspects are properly conducted, a quality assurance/quality control program must be established. This program must be established at the inception of a project and must be approved by the Colorado Department of Health.

Criterion 1: Disposal Site Suitability Requirements for Land Disposal

The purpose of this criterion is to specify the characteristics a disposal site must have to be acceptable for use as a near-surface disposal facility. The primary emphasis is given to isolation of wastes, a matter having long-term impacts, and to disposal site features that ensure the long-term performance objectives as opposed to short-term convenience or benefits. Due to the non-radioactive toxic constituents associated with radioactive wastes, the site should maintain its integrity for thousands of years. The site selection process shall be an optimization of these site characteristics.

A. The disposal site shall be capable of being characterized, modeled, analyzed, and monitored. Specific technical items to be addressed are set forth in the "License Application Guideline for Land Disposal of Low Level Radioactive Waste".

B. Within the region where the facility is to be located, a disposal site should be selected so that projected population growth and future developments are not likely to affect the ability of the disposal facility to meet the performance objectives of maintaining doses below regulatory limits.

C. Areas must be avoided having known or suspected natural resources which, if exploited, would result in failure to meet the performance objectives, especially the long-term integrity of the disposal site.

D. The disposal site must be removed from areas of flooding or ponding. Areas within a wetland or on a 100-year flood plain, as defined in Executive Order 11988, "Floodplain Management Guidelines", are prohibited.

E. Upstream drainage areas must be minimized to decrease the amount of runoff and limit the size of the probable maximum flood which could erode or inundate the waste disposal units.

F. The disposal site must provide sufficient depth to the water table that ground water intrusion, perennial or otherwise, into the waste will not occur. In no case will waste disposal be allowed below the highest predicted ground water table.

G. The hydrological unit used for disposal shall not discharge ground water to the surface within the vicinity of the disposal site. The hydrological unit shall be conducive to the continued immobilization and isolation of contaminants from usable ground water resources. Most likely materials to meet this immobilization are thick, relatively impermeable shales.

H. Areas must be avoided where tectonic processes such as faulting, folding, seismic activity or vulcanism may significantly affect the ability of the disposal site to meet the performance objectives or may preclude defensible modeling and prediction of long-term impacts. The disposal facility shall not be located near a capable fault which could cause disruption, displacement, or significant deformation of the facility after closure. Capable fault is defined in Section III (g) of Appendix A of 10 CFR Part 100.

I. The disposal site should be selected so that erosion, disturbance, and dispersion by natural forces over the long-term is minimized. Areas must be avoided where surface geologic processes such as mass wasting, erosion, slumping, landsliding, or weathering significantly affect the ability of the disposal site to meet the performance objectives or to preclude defensible modeling and prediction of long-term impacts.

J. The disposal site must not be located where nearby facilities or potential activities could adversely impact the ability of the site to meet the performance objectives. The combined effect of all facilities and activities within the region must not cause exposure to individuals in excess of the limits stated in the regulations.

K. Selection of the disposal site should consider co-location with other waste disposal operations so that proliferation of waste disposal sites is minimized.

L. The geochemical characteristics of the geologic strata at the site are to be compatible with the waste categories disposed at the site especially in terms of providing high adsorption, absorption, or chemical fixation of any wastes, both radiological and nonradiological constituents, that may migrate from the immediate disposal area.

Criterion 2: Disposal Site Design and Construction Requirements for Land Disposal

Criterion 2 specifies the technical aspects that must be considered in the design and construction of the disposal facilities. Such site design must be directed toward short-term control and long-term isolation of the waste materials and avoidance of the need for continuing active maintenance after site closure. The disposal site must be designed to complement and improve, where appropriate, the ability of the disposal site's natural characteristics to meet the performance objectives. Additionally, the disposal site design must be compatible with the site closure and stabilization plan and must provide reasonable assurance that the performance objectives will be met.

A. Waste material shall be placed below grade in specially excavated pits, trenches or cells.

B. Liners must be designed to minimize the seepage of toxic and radioactive materials into ground water or onto the land surface. In no case shall seepage of toxic and radioactive materials result in significant pollution. The term "significant pollution" means deterioration of existing ground water supplies from their current or potential use and/or exceedence of soil or surface water standards. The following shall be incorporated into design of the liner:

   1. Low permeability liners composed of natural or synthetic materials must be installed to minimize seepage. The liner permeability shall be no greater than 10^{-7} cm/sec. A leak detection system shall be installed directly beneath the liner to ensure adequate seepage detection. Where clay liners are proposed, the physical and geochemical properties of the materials must be included in the design considerations.

   2. Liner design must reduce short-term and long-term seepage to the maximum extent reasonably achievable.

C. The surface drainage design during operation and after closure must direct surface water away from the disposal units at velocities and gradients which will not result in erosion that will require active maintenance in the future. In no case shall potential inundation of the disposal units be allowed. The surface drainage design must use for its bases probable maximum precipitation and a resultant probable maximum flood.

D. Covers must be designed to minimize water infiltration, to direct percolating or surface water away from the disposed waste, to minimize wind and water erosion, to resist degradion by surface geological processes and biotic activity, and to minimize the impact of differential settlement. Additionally, if radium wastes are disposed of in a cell or trench the cover must be designed to retard any radioactive gases and reduce surface exhalation of radon emanating from the wastes to less than two picocuries per square meter per second. The following shall be considered in the cover design so the these factors can be properly incorporated.

   1. Cover thickness for Class C wastes is a minimum of 5 meters between the top of the waste and the top of the cover. Cover thickness may be less if an intrusion barrier is incorporated into the design for protection for thousands of years. Cover thickness for Class A and B wastes shall be based on evaluation of the above factors and must consider possible impacts to Class C disposed units.

2. Design of the cover shall be dependent upon all pertinent factors such as infiltration, root and animal penetration, and settlement.

3. Cover slopes shall be relatively flat after final stabilization to assure long-term stability. Final slopes should be as close to the natural slope of the areas as is practicable. In no case should slopes be steeper than 5(h):1(v) be used for final stabilization.

4. Cover protection shall be provided with appropriately sized rock to withstand the erosive forces from a probable maximum precipitation event, especially areas with concentrated flows. Protective cover material shall be of sufficient durability and thickness to provide assurance for long-term control of the waste material. Self-sustaining vegetative cover may be used in the final reclamation plan; however, primary control shall be a protective rock cover.

5. The entire disposal area shall be contoured to avoid areas of concentrated surface runoff or abrupt or sharp changes in slope gradient. Where concentrated runoff cannot be avoided, appropriate riprap protection shall be included in the design.

E. Design of the disposal facility shall incorporate potential affects of seismic events, especially in the design of final reclamation plans. The design event used would be a maximum vibratory ground motion at the site. This should be based upon an evaluation of the earthquake potential considering the regional and local geology, seismology, and specific characteristics of local subsurface materials.

F. Environmental monitoring system design shall include the detection and measurement of releases from the facility and shall include those factors listed in the environmental monitoring section (Criterion 4).

G. The disposal site must be designed to minimize the contact of water with waste during storage, the contact of standing water with waste during disposal, and the contact of percolating or standing water with wastes after disposal.

H. Construction activities for engineering works at the site will be conducted according to the designs and specifications approved by the Colorado Department of Health.

Criterion 3: Land Disposal Facility Operation and Disposal Site Closure

Facility operation and site closure must be conducted such that the performance objectives are fully met. Criterion 3 specifies minimum procedures to accomplish the performance objectives, especially Objective 3 (Protection of Individuals During Operations) and Objective 5 (Stability of the Site After Closure). Worker protection and contaminant control are paramount during site operation and closure.

A. The boundaries and physical dimensions of the disposal site and each cell or unit within the site must be accurately located in space by a land survey and map. The corners of those units closest to the surface must be marked in a fashion that easily delineates the boundaries of each unit. Three permanent survey points will be constructed at the site. These markers will be referenced to USGS or NGS control points and must provide both horizontal and vertical control.

B. A strip of land at least 30 meters wide, located around the perimeter of the disposal site, must be set aside to function as a buffer zone. In the direction of ground water flow, this buffer zone shall be 60 meters wide. This buffer zone shall provide space for environmental monitoring and mitigative measures if needed.

C. Only materials containing or contaminated with radioactive materials shall be disposed of at the disposal site.

D. Class A waste which does not meet the stability requirements set forth in RH 4.23 of the regulations must be segregated from other wastes by placing it in disposal units which are sufficiently separated from the units for other waste classes so that any interaction between unstabilized Class A wastes and other wastes will not result in the failure to meet the performance objectives. Waste designated as Class C must be disposed of so that the top of the Class C waste is a minimum of 5 meters below the surface, or must be covered with a barrier that will prevent inadvertent intrusion.

E. Wastes must be emplaced in a manner that maintains the package integrity during emplacement, minimizes the void spaces between packages, and permits the void spaces to be filled.

F. Void spaces between waste packages must be filled with earth or other material to reduce future subsidence within the pits, trenches or cells.

G. As each cell reaches its design capacity for waste, it shall be stabilized, covered, and closed according to the approved site closure plan.

H. Waste must be placed and covered in a manner that limits the radiation dose rate at the surface of the cover to levels that at a minimum will permit the licensee to comply with all provisions of Colorado's "Rules and Regulations Pertaining to Radiation Control".

I. Active waste disposal operations must not have an adverse effect on previously stabilized and closed units.

J. Waste disposal operations shall be conducted according to an operations and procedures manual approved by the Colorado Department of Health. This manual shall contain a radiation safety program for control and monitoring of toxic and radioactive effluents.

K. Disposal unit closure shall follow the site closure plan approved by the Colorado Department of Health.

Criterion 4: Environmental Monitoring

Primary emphasis of the environmental monitoring program is directed toward gathering data so the potential health effects and environmental impacts can be properly evaluated. If migration of contaminants is properly identified, corrective measures can then be taken to mitigate the problem.

A. Before the review of the initial application, a broad program of preoperational monitoring will be conducted to establish background levels of basic environmental parameters for the disposal site. This program will include studies of the meteorology, hydrology, geology, geochemistry, hydrogeology, seismology, and ecology. For those parameters that vary seasonally, data collection must cover a minimum of 12 months. Where appropriate, this information can be supplemented with published material and local, documented knowledge.

B. Evaluations in conjunction with the above studies shall be performed to establish background levels for critical radionuclides as well as organic and inorganic compounds.

C. During the land disposal facility site construction and operation the licensee shall maintain a monitoring program. Measurements and observations must be made and recorded to provide data to evaluate the potential health and environmental impacts during both the construction and the operation of the facility and to enable the evaluation of long-term effects and the need for mitigative measures. The monitoring system must be capable of providing early warning of releases of toxic material and radionuclides from the disposal site before they leave the site boundary.

D. After the disposal site is closed, the licensee responsible for post-operational surveillance of the disposal site shall maintain a monitoring system based on the operating history and the closure and stabilization of the disposal site. The monitoring system must be capable of providing early warning for releases of toxic substances or radionuclides from the disposal site before they leave the site boundary.

E. The emphasis of the monitoring program shall be toward quantifying background conditions as much as possible, but subjective evaluations and interpretations shall be included as a part of the program. If the monitoring program indicates that the performance objective relating to the release of material may not be met, this shall be reported within 10 days to the Colorado Department of Health.

F. The licensee must have plans for taking corrective measures if migration of toxic materials or radionuclides would indicate that performance objectives may not be met.

G. If other disposal activities are located in the immediate site area, the monitoring program must assure that toxic or radionuclide migration from the cells or disposal area can be effectively monitored and that such monitoring is not masked by other activities.