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United States Department of Energy

Disposal Site Characterization Report for the Alternate Uranium Mill Tailings Disposal Site in Bodo Canyon Near Durango, Colorado

Draft

May, 1985

Uranium Mill Tailings Remedial Action Project

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DISPOSAL SITE CHARACTERIZATION REPORT

FOR THE

ALTERNATE URANIUM MILL TAILINGS DISPOSAL SITE

IN

BODO CANYON

NEAR

DURANGO, COLORADO

MAY, 1985

Uranium Mill Tailings Remedial Action Project Office
Albuquerque Operations Office
Department of Energy
Albuquerque, New Mexico 87108

Approved

____
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1.0 INTRODUCTION

The Uranium Mill Tailings Radiation Control Act of 1978 (PL95-604) requires the Department of Energy (DOE) to assess the degree of radiological contamination at the sites of certain former uranium mill operations and to conduct remedial actions "to stabilize and control such tailings in a safe and environmentally sound manner and to minimize or eliminate radiation health hazards to the public". One alternative remedial action is to relocate the tailings and contaminated material to a site other than the existing site. This report is an assessment of the present conditions and available data at the alternate disposal site identified as Bodo Canyon, which is one of two sites being evaluated for the possible relocation of the tailings and contaminated materials from the Durango processing site.

1.1 PURPOSE AND SCOPE

This report summarizes the available data that are pertinent to the assessment of existing conditions and the design of the remedial action plan. Some data collection activities, such as ground-water quality and level measurements, are ongoing. Data from those activities will be incorporated into the final DSCR and added to the site characterization data base.

2.0 SITE DESCRIPTION

2.1 LOCATION

The proposed alternate disposal site is located approximately 1.5 miles due southwest of the Durango processing site in an ephemeral drainage basin known as Bodo Canyon. The site encompasses about 80 acres in the eastern half of Section 36, R10W, T35 N and the western half of Section 31, R9W, T34 1/2N in La Plata County, Colorado. The site is approximately 2 miles from U.S. Highway 160/550 and about 0.5 mile north of County Road 211 (Bodo Canyon Road) which connects to U.S. Highway 160/550 (Figure 2.1).

2.2 PHYSICAL DESCRIPTION

The Bodo Canyon area is characterized by hills and ridge lines with moderate slopes (up to 20 percent) separated by small canyons and vales in the foothills at the southern end of the San Juan Mountains. The disposal site, is at an elevation of about 7100 feet, and is located in a gently sloping subbasin near the upper west end of the Bodo Canyon drainage (Figure 2.2). Maximum topographic relief across the site is about 90 feet. An east-west-trending ridge north of the site separates the site from surface drainages off Smelter Mountain. Almost all surface drainage from the site is discharged to an unnamed valley north of the site which drains into the Animas River.

Natural vegetation in Bodo Canyon ranges from grasslands to sagebrush on bottomlands to foothills covered with scrub oak, rabbitbrush, and other shrubs. Scattered ponderosa pine, pinon pine, and juniper occur throughout the area but are especially prevalent on the upper slopes.

The Bodo Canyon area is part of a land parcel deeded through purchase to the State of Colorado by The Nature Conservatory for preservation as deer and elk winter rangeland. The area is managed by the Colorado Division of Wildlife (CDW). Use of the area for any other purpose requires prior approval of the CDW and concurrence by The Nature Conservancy.

Current access to the Bodo Canyon site from the Durango mill site is via U.S. Highway 160/550 to County Road 211 (Bodo Canyon Road) to County Road 212 thence eastward into the site. Both County Roads 211 and 212 are relatively narrow gravel roads. County Road 211 extends westward through Bodo Canyon and Ridges Basin for approximately eight miles where it then intersects County Road 141 (Wildcat Canyon). County Road 212 extends from 211 to the top of Smelter Mountain. During remedial action, access from the designated site to County Road 211 would be via a new access road constructed from the raffinate ponds area directly to County Road 211.

2.3 OWNERSHIP

The sections of land on which the disposal site is located are owned by the State of Colorado as a part of the Bodo Canyon Wildlife Refuge. The

The surrounding area is owned by the State of Colorado either as Division of Wildlife land or as school lands. The disposal site area is being appraised by the U.S. Army Corps of Engineers.

2.4 PHYSIOGRAPHY AND TOPOGRAPHY

The Bodo Canyon disposal site is located at the northern end of the San Juan Basin which can be characterized as consisting of southwest-trending hogbacks that have steep northern slopes and more gentle southern slopes. The highest ridges in the area exceed 8000 feet above mean sea level with total relief being in excess of 1200 feet. The valleys between the hogbacks are drained by intermittent or ephemeral streams with their channels deeply incised into the underlying alluvium and shales.

The proposed Bodo Canyon disposal site is located southwest of the Durango processing site in a gently sloping subbasin in and near the upper west end of the 4.5-square-mile Bodo Canyon drainage area. Elevations across the disposal site range from highs of approximately 7125 feet at points along the southern boundary to as low as 7035 feet in the small northeast-trending gully on the north side of the site (see Figure 7.1 of Section 7.0). A major portion of the surface area of the site slopes toward the upper reach of this gully where a small embankment has been constructed to capture surface drainage and form a watering pond for livestock and wildlife. Gradients across the site are variable, ranging from less than 2 percent to more than 15 percent. The plateau-like area is bounded to the north by a small steep-sided ephemeral stream and to the

west and south by the main Bodo Canyon drainage, itself a steep-sided ephemeral stream, the bed of which is, in some places, over 100 feet lower than the site.

Prior to revegetation and stabilization by the Colorado Division of Wildlife, there were severe erosion problems in this area due to the steep hillsides and channels. However, the area is now considered to be a zone of moderate erosion that will have a low annual soil loss as long as it is not overgrazed or otherwise denuded of vegetation.

2.5 SUBSURFACE GEOLOGY

2.5.1 Structural geology

The Bodo Canyon site is located on the extreme eastern edge of the Colorado Plateau physiographic province. It lies on the southeast limb of the Durango anticline which is a relatively minor structural feature superimposed on the Hogback Monocline along the north-northwest boundary of the San Juan Basin (Figure 2.3). The bedrock in Bodo Canyon dips to the southwest at an angle that varies between 5 and 15 degrees. Dips farther to the south of the site are in the same direction but range up to as much as 40 degrees from the horizontal.

The northern San Juan Basin shows evidence of extensive faulting along its northeastern and eastern boundaries but areas along its northwestern boundary, including the Hogback Monocline, have not been subjected to major faulting. However, a series of northeast trending faults, thought to have been formed during the Laramide Orogeny, have been mapped in the Durango area. Among these, a northeast trending fault, herein called the "Ridges Basin Fault" has been mapped (Zapp, 1949) from Ridges Basin into Bodo Canyon. It has been postulated by some (CGS, 1981; SHB, 1984a) that the Ridges Basin Fault may extend into or near the Bodo Canyon disposal site. Several small faults with displacements of less than 10 feet are exposed in a man-made cut slope to the south of the site, but are not thought to be related to the fault mapped by Zapp since their displacements are in the opposite direction (Dames and Moore, 1983b). Thus, all evidence available at this time indicates that the fault dies out just south of the site. This has been confirmed by field reconnaissance, low sun reconnaissance, and trenching at the Bodo Canyon site.

2.5.2 Site stratigraphy

The Bodo Canyon disposal site is underlain by sedimentary rocks which are thought to have been formed from deposits originally laid down at the bottom of a quiet inland sea during the Upper Cretaceous Age. Bedrock units evidenced by rock outcrops in the Bodo Canyon area include (from youngest to oldest): The Lewis

Shale, a dark-gray shale; the Cliff House Sandstone, a gray rock unit grading from sandstone to mudstone to shale; the Menefee Formation, a highly variable unit made up of light-gray sandstones, siltstones and shales; and the Point Lookout Sandstone, a light to yellowish-gray sandstone. The last three rock units mentioned are more generally referred to as the Mesa Verde Formation, and immediately underlie the Bodo Canyon disposal site with the Cliff House Sandstone being nearest the surface (Figure 2.4).

The lowermost Mesa Verde rock unit, the Point Lookout Sandstone, is a thin-bedded to massive, 270- to 400-foot-thick sandstone unit. The erosion-resistant Point Lookout Sandstone caps the Smelter Mountain hogback located southwest of the existing tailings site and northeast of Bodo Canyon. Overlying the Point Lookout Sandstone is a complex assemblage of lenticular sandstone beds, dark-colored shale and siltstone beds, and coal beds called the Menefee Formation. The Menefee Formation ranges from 250 to 600 feet in thickness and contains the major coal beds that occur in the Durango area. The 20- to 410-foot-thick Cliff House Sandstone, overlying the Menefee, consists of interbedded calcareous sandstone, siltstone, and silty shale. Although a resistant, ledge-forming unit in the vicinity of Mesa Verde National Park, the Cliff House Sandstone in the area southwest of Durango is much less resistant to erosion than is the underlying Point Lookout Sandstone.

Surficial materials consist of as much as 65 feet of unconsolidated quaternary alluvial and colluvial deposits made up of silty clay and silt soils that are locally interbedded with layers of mixed sandstone and shale bedrock fragments. The soils generally can be classified (in the Unified Soils Classification System) as varying between low plasticity silts (ML) and clays (CL) with some sand. The surface soils are, in turn, underlain by 5 to 35 feet of fractured weathered shale derived from the lower, shale dominated transitional portion of the Cliff House sandstone which, at a depth of about 140 feet or less, grades into the shales of the Menefee Formation. The details of subsurface geotechnical and hydrological investigations and laboratory testing are discussed further in Sections 5.0 and 7.0, respectively.

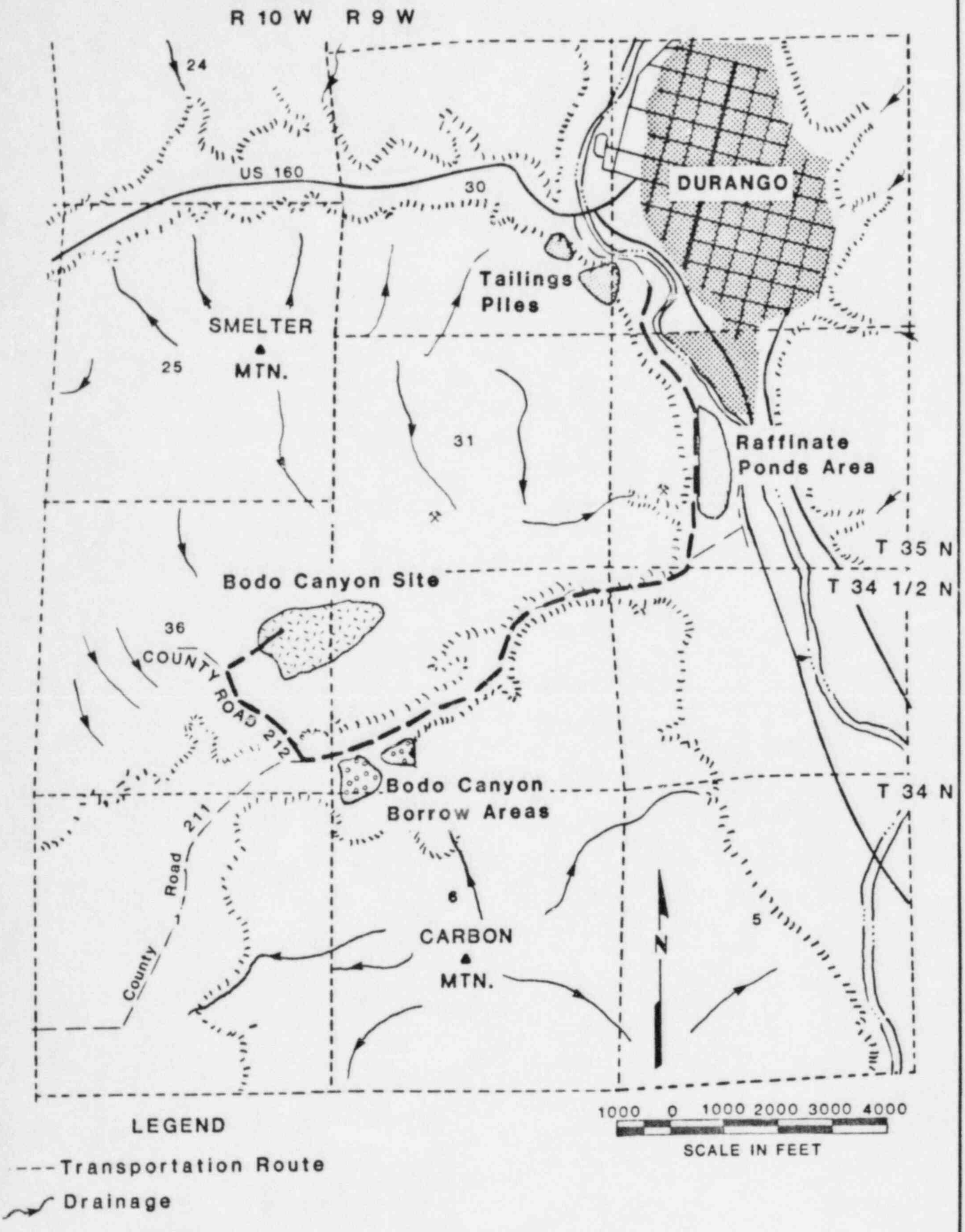


FIGURE 2.1
LOCATION OF BODO CANYON SITE

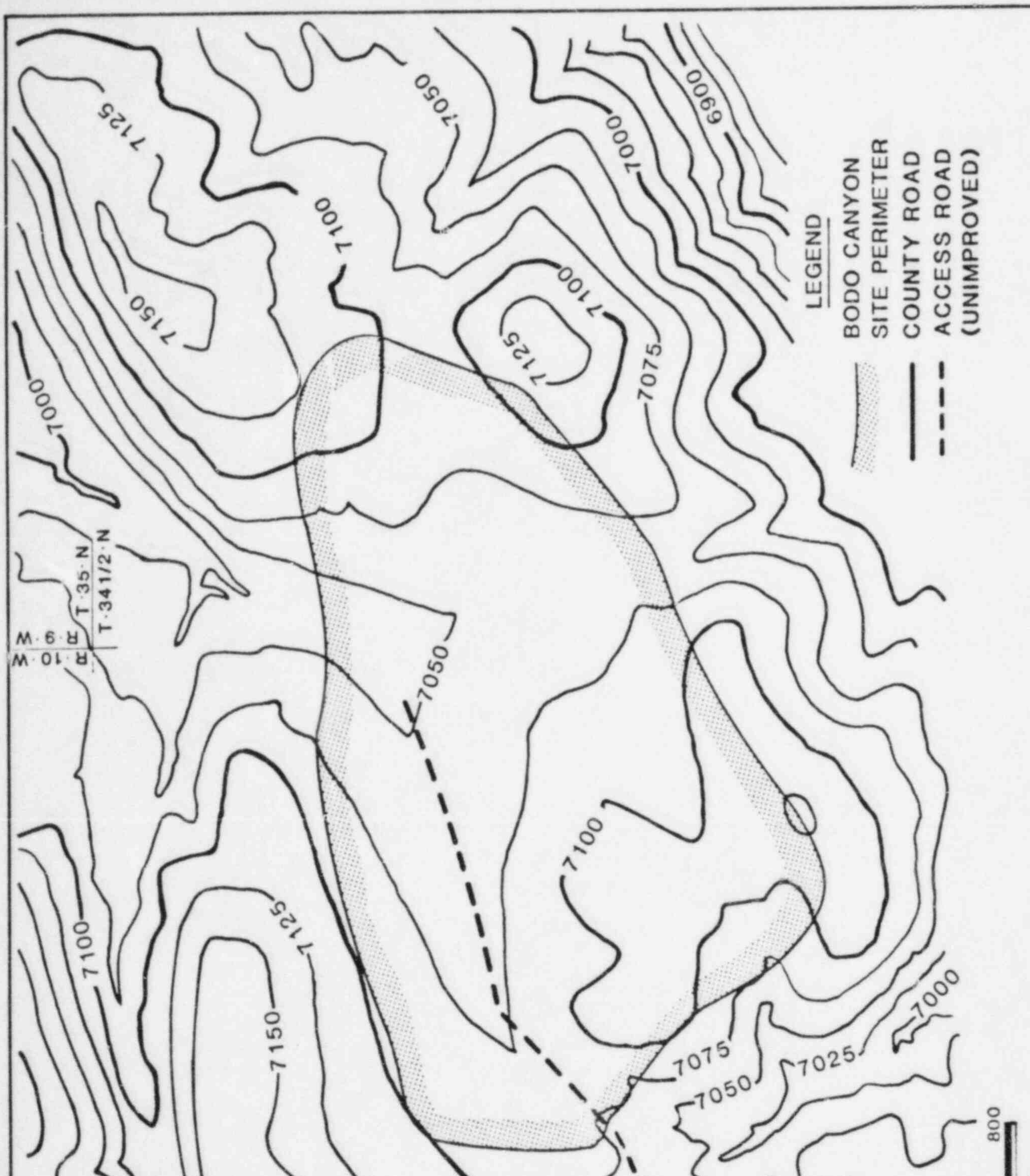


FIGURE 2.2
VICINITY MAP - BODO CANYON SITE

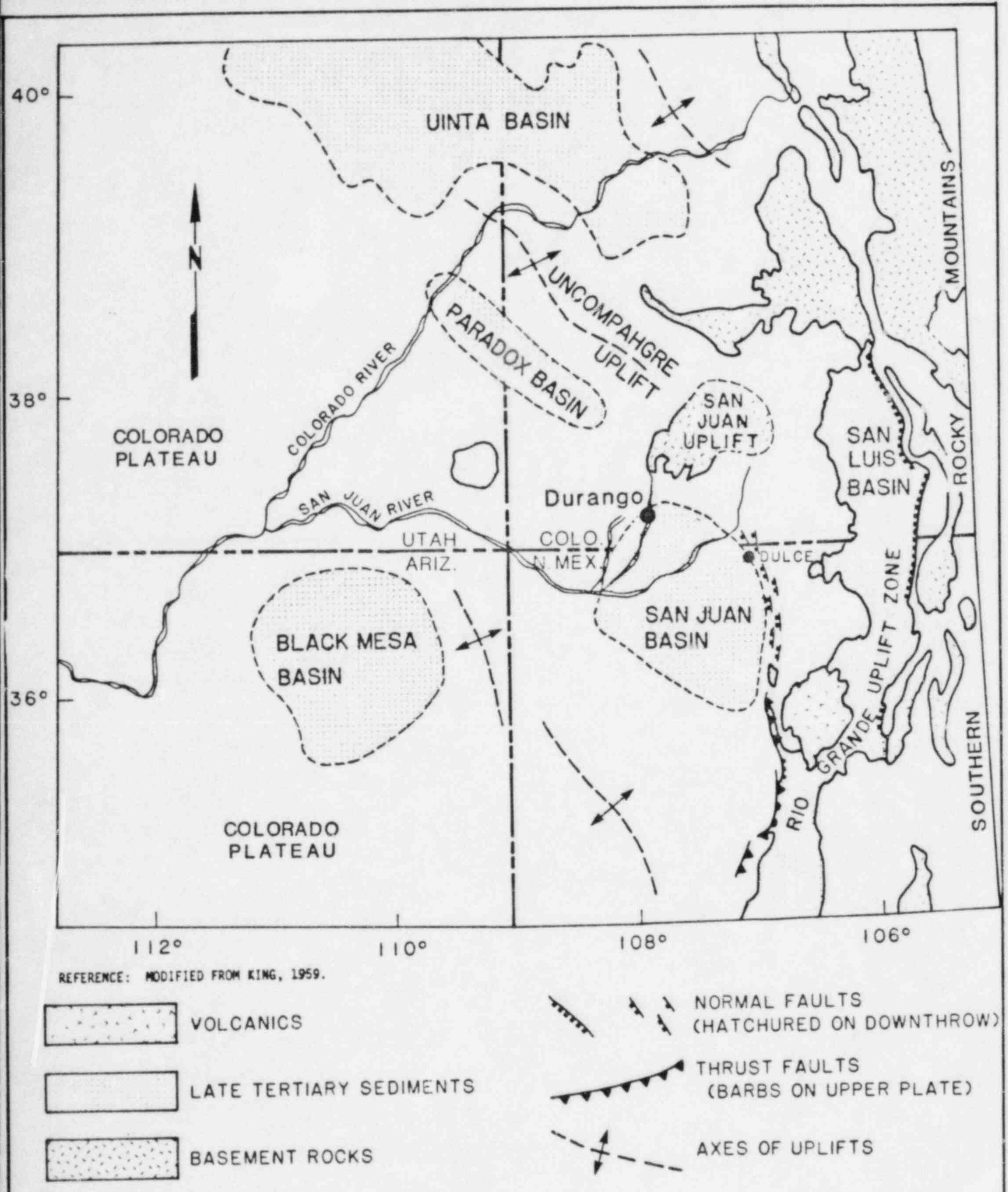


FIGURE 2.3
PHYSIOGRAPHY AND STRUCTURAL GEOLOGY OF THE FOUR CORNERS REGION

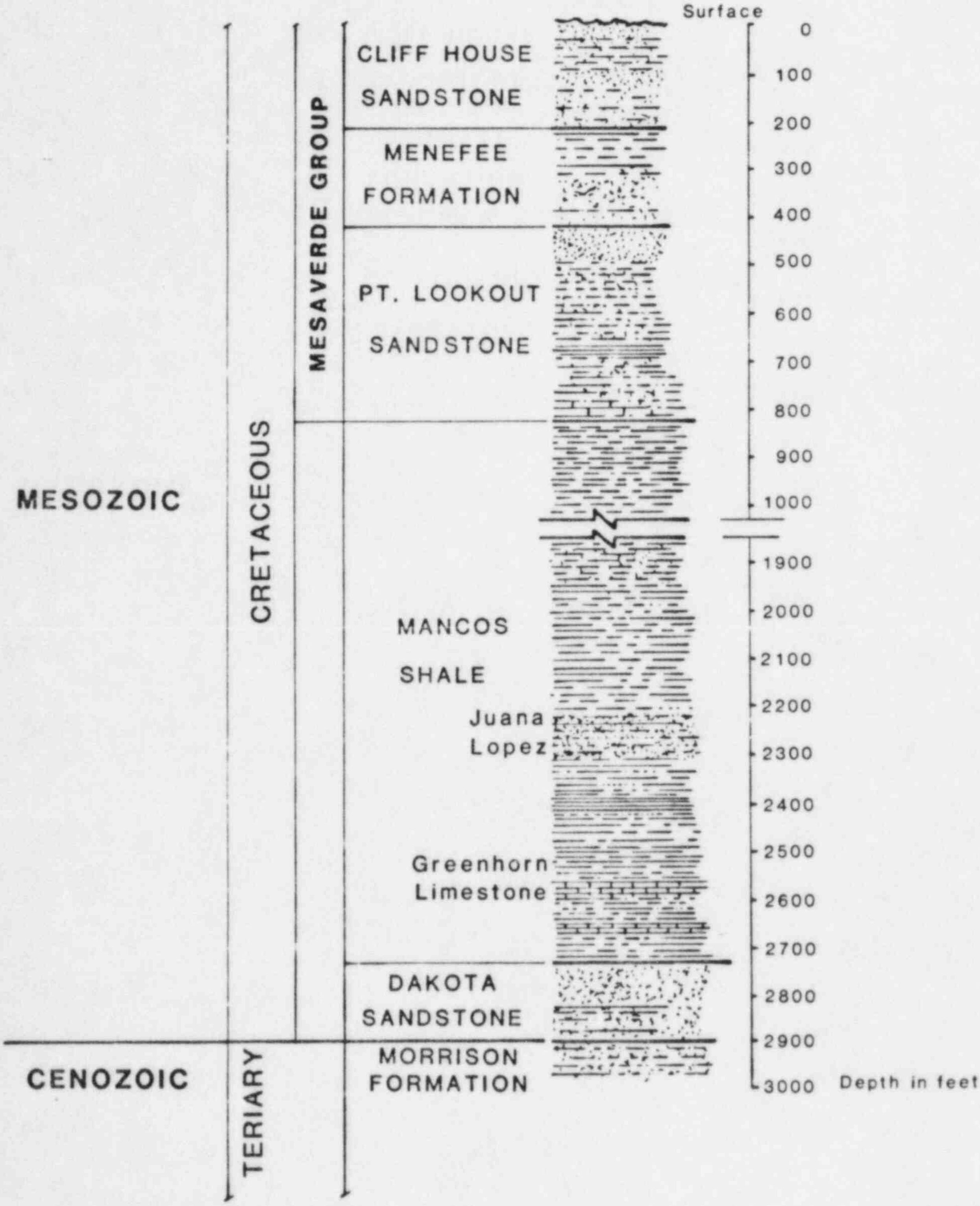


FIGURE 2.4

DETAILED STRATIGRAPHIC COLUMN OF CRETACEOUS ROCKS AT THE BODO CANYON SITE

3.0 LAND SURVEY DATA

3.1 TOPOGRAPHIC SURVEY

The Bodo Canyon disposal site area was aerially surveyed by Kougle and Pouls Engineering, Inc. of Albuquerque, New Mexico, on October 6, 1981. The same company conducted the ground surveys on the same date. The topographic map was prepared with a scale of one inch equals 400 feet with a five foot contour interval. A copy of the map is on file in the UMTRA Project Office in Albuquerque. Additional topographic coverage of the Bodo Canyon disposal site and County Road 211 from Highway 160/550 to County Road 212 has been prepared by Land Surveying Company, Santa Fe, New Mexico, at a scale of one inch equals 200 feet with two-foot contour intervals. The site has also been digitized at a grid spacing of 25 feet. This additional topographic coverage is contained in Appendix D, Laboratory Test Date - Foundation Soils.

The topographic map elevations are based on the 1927 North American datum for vertical control. The benchmark is a USGS brass cap monument located in the northwest 1/4 of Section 29, Township 35N, Range 9W. This monument is located on 8th Street between Main Avenue and the railroad in Durango, Colorado.

3.2 AERIAL PHOTOGRAPHS

Copies of the aerial photographs used to prepare the one inch equals 400 feet topographic map are in the UMTRA Project Office in Albuquerque, New Mexico. Aerial photographs in support of the revised topographic mapping are also on file with the UMTRA Project Office. These photos indicate the typical features of the area.

3.3 DATA EVALUATION

The topographic coverage by the Land Surveying Company will be satisfactory for preparation of site conceptual design should Bodo Canyon be selected as the disposal site. The U.S. Corps of Engineers, in Omaha, Nebraska, is in the process of reviewing the legal description of the Bodo Canyon disposal site, site access, and utility easements as part of their site appraisal.

4.0 RADIATION DATA

4.1 BACKGROUND MEASUREMENTS

An environmental characterization program to establish background radiation levels and variations in the environs of the Bodo Canyon site and the transportation corridor was initiated in October, 1982, and continued through October, 1983. The radiological sampling program for Bodo Canyon is summarized in Table 4.1. The radiological characterization program included measurement of the radionuclide concentration of airborne particulates; radionuclide concentrations in surface and subsurface soils, surface sediments, vegetation, and animals; external gamma exposure rate levels; and ambient radon-222 (radon) concentrations. The sensitivity of instrumentation used for these background measurements met specifications of the U.S. Nuclear Regulatory Commission (NRC, 1980). Baseline surface- and ground-water samples were taken and analyzed as part of the water-quality program (see Sections 5.0 and 6.0). Water sample analyses included natural uranium, radium-226 radium-228, lead-210, polonium-210, and thorium-230.

Figure 4.1 identifies five monitoring stations used during a study to determine existing radioactive air particulate concentrations in the Bodo Canyon area. Three monitoring stations were located at the Bodo Canyon site and one monitoring station was located at each of two remote locations. The remote locations were approximately 1.5 miles east of the Bodo Canyon site (remote east sampler no. 4) and approximately 5 miles west of

the Bodo Canyon site (remote west sampler no. 5). Results of radioactive air particulate measurements at these five monitoring stations for one year are shown in Table 4.2 (Dames and Moore, 1983b; JEG, 1984). Soil samples were also taken at these five locations and results of Ra-226 concentration-analyses are shown in Table 4.3 (Dames and Moore, 1983b).

Additional sampling locations at the Bodo Canyon site for radionuclide concentrations in soil, sediments, and biota are shown in Figure 4.2. Data are presented in Tables 4.4 through 4.8 (Dames and Moore, 1983b).

Four external gamma exposure rate measurements were made at the Bodo Canyon site in September, 1983, with a Reuter Stokes RSS-111 pressurized ionization chamber (PIC) at locations shown in Figure 4.3. Measurements resulted in a mean and one standard deviation gamma exposure rate of 15.7 $\pm$ 0.4 microR/hr (JEG, 1984). The RSS-111 is considered to be the standard instrument for gamma exposure rate measurements in the field.

In contrast, Table 4.9 presents data from a study by Argonne National Laboratory (ANL, 1983) which measured slightly higher gamma exposure rates at the Bodo Canyon site, possibly caused by moisture damage to thermoluminescent dosimeters from heavy snows. The exposure period during this study was approximately 6 months, from October, 1982, to April, 1983. The September, 1983, PIC measurements in Bodo Canyon are considered to be more representative of site conditions. Thermoluminescent dosimeter measurements by Argonne at the transportation route locations shown in Figure 4.2 and Table 4.9 are considered to be representative because moisture damage did not occur.

The Argonne study also measured the ambient radon concentrations using Terradex Track-Etch detectors for the same 6-month period at the five monitoring stations shown in Figure 4.1 and along the transportation route shown in Figure 4.3. Average radon concentrations are presented in Table 4.9. As expected, the ambient radon concentration as well as the gamma exposure rate are closely correlated with distance from the tailings pile along the transportation route. The Bodo Canyon area was snow-covered during much of the Track-Etch exposure period in the field. Radon emanation is reduced by both snow cover and frozen ground; therefore, the radon concentrations in Table 4.9 may be lower than radon concentrations measured during snow-free periods of the year.

A year-long Terradex Track-Etch study was conducted from December 15, 1983, to January 11, 1985, to determine the spatial variability of background radon air concentration in the vicinity of the Durango tailings site (DOE, 1984). One radon monitoring station was located at the west edge of the Bodo Canyon site, near air particulate monitoring station No. 1 as depicted in Figure 4.1. Track-Etch cups were changed and analyzed quarterly during the year-long period. The study resulted in an annual average radon air concentration of 0.50 pCi/l at the Bodo Canyon monitoring location.

4.2 ADDITIONAL SITE RADIOLOGICAL CHARACTERIZATION

The quality of data acquired from the Bodo Canyon site is good, and collection of data for radiological site characterization in Bodo Canyon is complete.

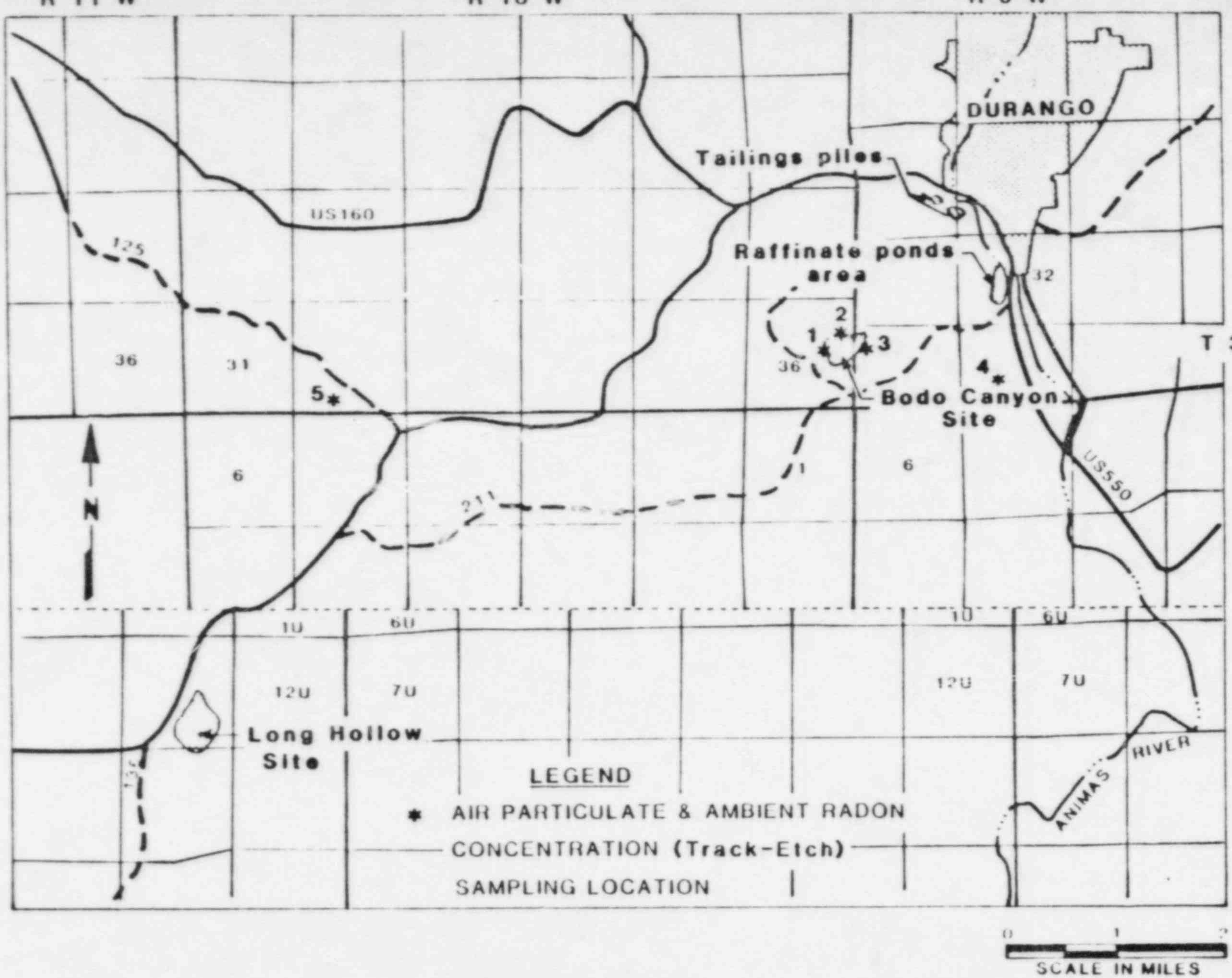


FIGURE 4.1
RADIOLOGICAL AIR-PARTICULATE SAMPLING LOCATIONS
FOR BODO CANYON AND LONG HOLLOW ALTERNATE SITES

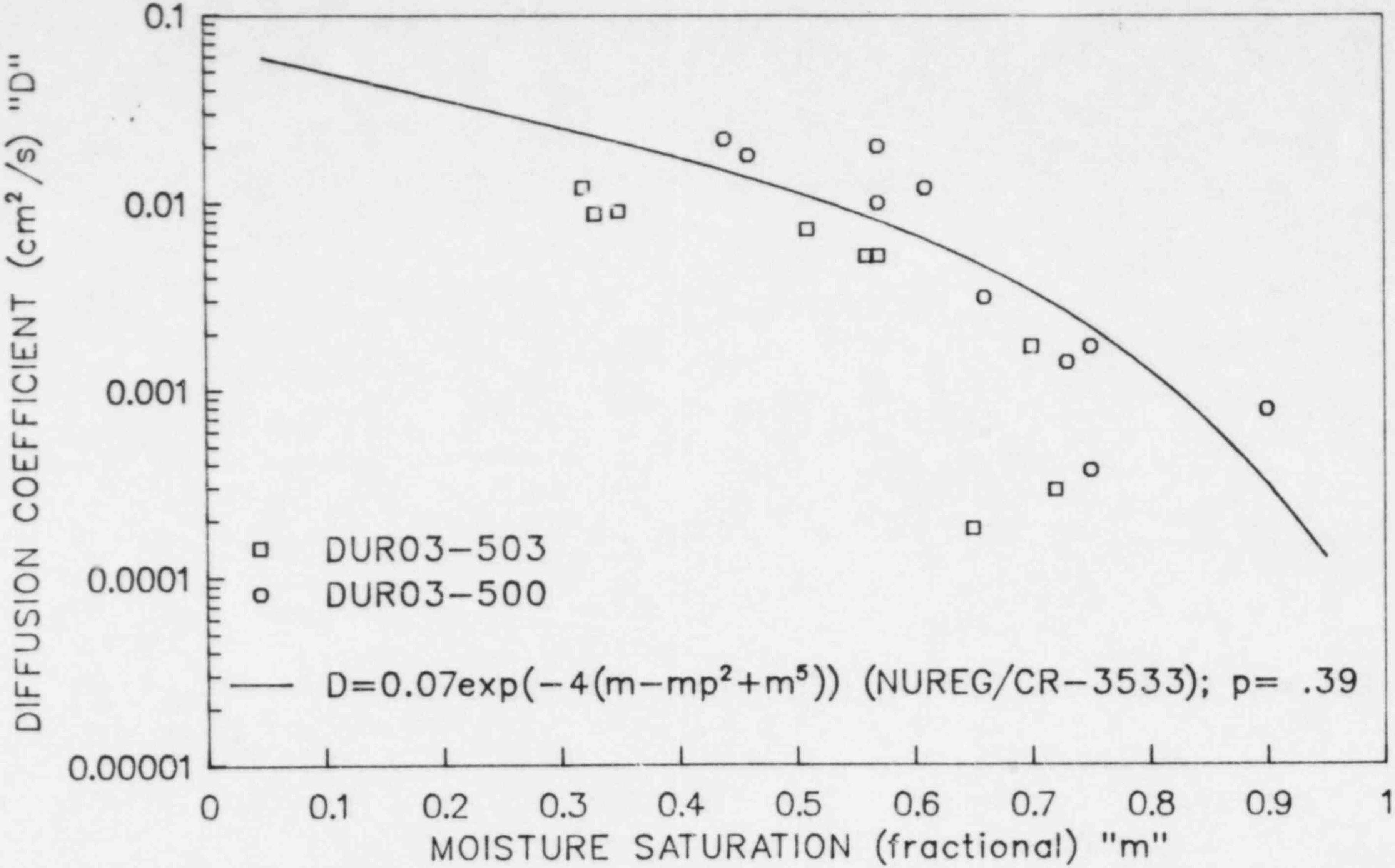


FIGURE 4.2

DIFFUSION COEFFICIENT (cm^2/s)"D"

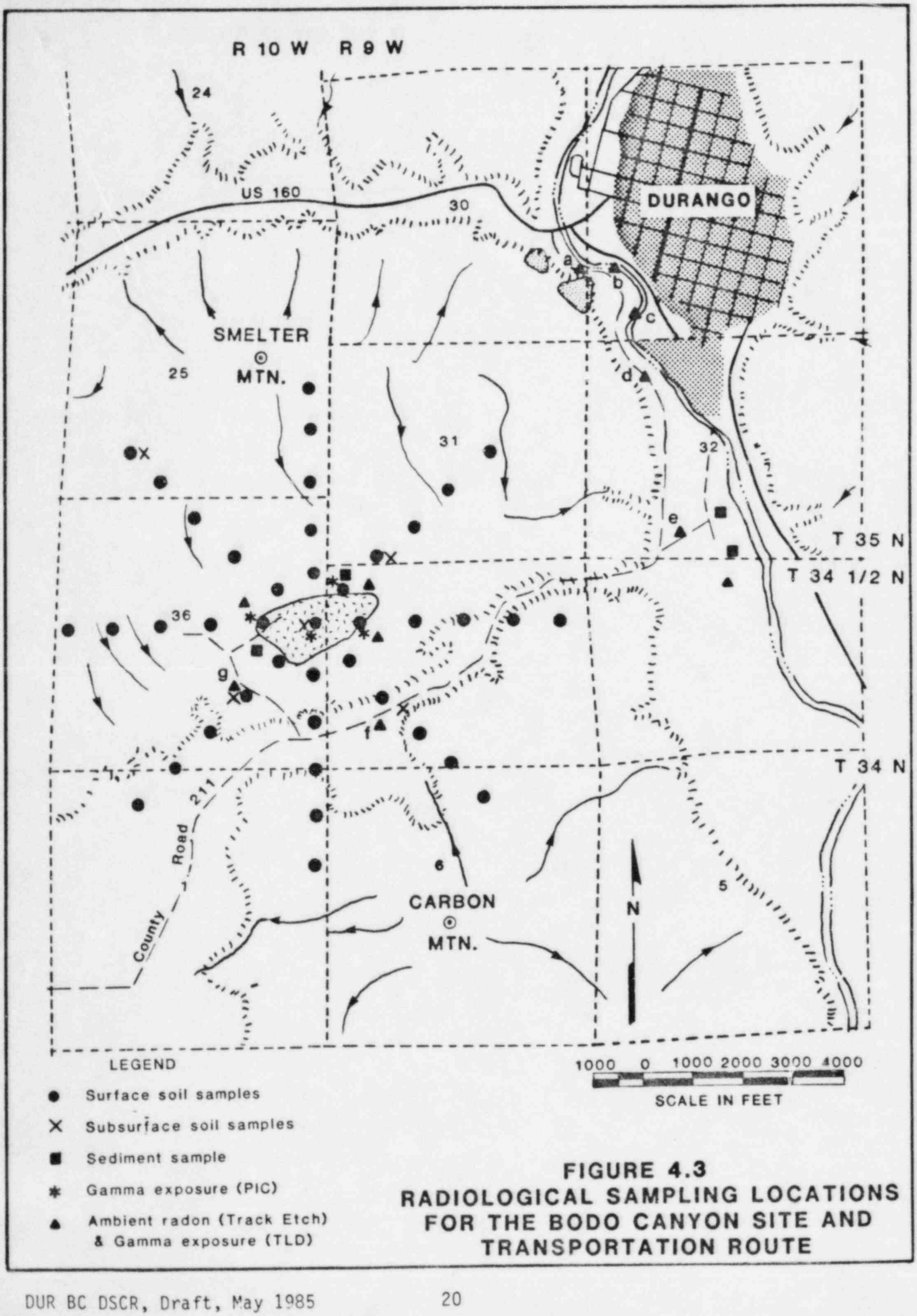


FIGURE 4.3
RADIOLOGICAL SAMPLING LOCATIONS FOR THE BODO CANYON SITE AND TRANSPORTATION ROUTE

Table 4.1 Summary of radiological sampling program

Sampling	Method	Number of sampling points	Frequency
Air particulate	Eberline Model RAS-1 regulated air samplers	5	Continuous (12 months)
Soil	Surface - ring method	46	Once
	Subsurface - trench method	13	Once
Sediment	Ring method	4	Once
Biota vegetation	------	3	3 times/year (spring, summer, fall)
Wildlife	------	3	Once
External gamma	Thermoluminescent dosimeters (TLDs)	10	Continuous (6 months)
External gamma	Pressurized ionization chamber	4	Once
Ambient air radon-222	Track-etch	10	Continuous (6 months)

Ref. Dames and Moore, 1983b; ANL, 1983; JEG, 1983.

Table 4.2 Radionuclide airborne particulate concentrations at the Bodo Canyon site and at remote locations

		Concentration (pCi/l)[a]				
		Bodo Canyon			Remote stations	
Radionuclide	Quarter	West Sampler No. 1	North Sampler No. 2	East Sampler No. 3	Remote east Sampler No. 4	Remote west Sampler No. 5
U-nat	1	4.8E-08 ± 2.4E-08[b]	0 ± 2.9E-08	5.2E-08 ± 2.6E-08	5.0E-08 ± 2.5E-08	0 ± 2.8E-08
	2	0 ± 2.5E-08	0 ± 2.2E-08	0 ± 2.3E-08	4.8E-08 ± 2.4E-08	0 ± 2.8E-08
	3	5.3E-08 ± 2.7E-08	8.0E-08 ± 2.7E-08	4.5E-08 ± 2.3E-08	8.2E-08 ± 4.1E-08	8.2E-08 ± 4.1E-08
	4	0 ± 3.0E-08	4.0E-08 ± 2.0E-08	7.1E-08 ± 2.4E-08	5.8E-08 ± 1.4E-08	6.3E-08 ± 3.1E-08
Average		2.5E-08 ± 1.3E-08	3.0E-08 ± 1.2E-08	4.2E-08 ± 1.2E-08	6.0E-08 ± 1.4E-08	3.6E-08 ± 1.6E-08
Th-230	1	7.2E-08 ± 2.4E-08	8.6E-08 ± 2.9E-08	7.3E-07 ± 5.2E-08	8.5E-06 ± 5.0E-07	2.5E-07 ± 2.8E-08
	2	5.1E-08 ± 2.5E-08	0 ± 2.2E-08	0 ± 2.3E-08	7.2E-08 ± 2.4E-08	5.5E-08 ± 2.8E-08
	3	5.3E-08 ± 2.7E-08	6.8E-08 ± 2.3E-08	6.8E-08 ± 2.3E-08	2.1E-07 ± 4.1E-08	1.6E-07 ± 4.1E-08
	4	5.9E-08 ± 3.0E-08	8.0E-08 ± 2.0E-08	9.4E-08 ± 4.7E-08	5.8E-08 ± 1.4E-08	9.4E-08 ± 3.1E-08
Average		5.9E-08 ± 1.3E-08	5.9E-08 ± 1.2E-08	2.2E-07 ± 1.9E-08	2.2E-06 ± 1.3E-07	1.4E-07 ± 1.6E-08
Ra-226	1	6.0E-08 ± 1.2E-08	2.3E-08 ± 2.3E-08	0 ± 2.1E-08	0 ± 2.0E-08	0 ± 2.2E-08
	2	0 ± 2.0E-08	0 ± 1.8E-08	0 ± 1.8E-08	2.1E-08 ± 1.9E-08	2.2E-08 ± 2.2E-08
	3	0 ± 2.1E-08	0 ± 2.1E-08	0 ± 3.3E-08	0 ± 3.3E-08	8.2E-08 ± 3.3E-08
	4	1.1E-07 ± 2.4E-08	0 ± 1.6E-08	6.6E-08 ± 1.9E-08	5.2E-08 ± 1.2E-08	2.8E-08 ± 2.5E-08
Average		4.3E-08 ± 9.9E-09	5.8E-09 ± 9.8E-09	1.7E-08 ± 1.2E-08	1.8E-08 ± 1.1E-08	3.3E-08 ± 1.3E-08
Pb-210	1	2.0E-05 ± 9.6E-07	2.0E-05 ± 1.1E-06	2.3E-05 ± 1.0E-06	2.0E-05 ± 1.0E-06	2.0E-05 ± 1.1E-06
	2	1.4E-05 ± 7.6E-07	1.1E-05 ± 4.4E-07	1.5E-05 ± 6.8E-07	1.5E-05 ± 7.2E-07	1.4E-05 ± 8.3E-07
	3	1.3E-05 ± 7.9E-07	1.5E-05 ± 6.8E-07	1.5E-05 ± 6.8E-07	2.1E-05 ± 1.2E-06	1.7E-05 ± 8.2E-07
	4	1.8E-05 ± 8.9E-07	1.1E-05 ± 6.0E-07	1.6E-05 ± 7.1E-07	1.0E-05 ± 4.3E-07	1.4E-05 ± 6.3E-07
Average		1.6E-05 ± 4.3E-07	1.4E-05 ± 3.7E-07	1.7E-05 ± 3.9E-07	1.7E-05 ± 4.4E-07	1.6E-05 ± 4.3E-07

[a] The error is twice the counting standard deviation.
[b] E-x is equivalent to 10^{-x}.

Ref. Dames and Moore, 1983b, and JEG, 1984.

Table 4.3 Radionuclide concentrations in surface soil samples from air-particulate sampling locations

Location	Radionuclide	Concentration (pCi/g dry wt[a])
Air-particulate location No. 1	U-238	1.2 ± 0.1
	Th-230	1.3 ± 0.1
	Ra-226	1.3 ± 0.1
	Pb-210	0.7 ± 0.1
Air-particulate location No. 2	U-238	2.0 ± 0.1
	Th-230	2.3 ± 0.1
	Ra-226	1.4 ± 0.1
	Pb-210	4.2 ± 0.2
Air-particulate location No. 3	U-238	1.3 ± 0.1
	Th-230	1.4 ± 0.1
	Ra-226	1.6 ± 0.1
	Pb-210	1.3 ± 0.2
Air-particulate location No. 4	U-238	0.9 ± 0.1
	Th-230	1.0 ± 0.1
	Ra-226	1.0 ± 0.1
	Pb-210	2.6 ± 0.2
Air-particulate location No. 5	U-238	2.0 ± 0.1
	Th-230	2.4 ± 0.1
	Ra-226	1.8 ± 0.1
	Pb-210	3.2 ± 0.2

[a] The error is twice the counting standard deviation.

NOTE: Sample locations are indicated on Figure 4.1.

Ref. Dames and Moore, 1983b.

Table 4.4 Radionuclide concentrations in surface soil samples from Bodo Canyon

Sample direction in meters	Radionuclides	Concentration (pCi/g dry wt[a])
East		
300	Ra-226	1.3 ± 0.1
600	Ra-226	1.0 ± 0.1
900	Ra-226	1.3 ± 0.1
1200	Ra-226	1.3 ± 0.1
1500	Ra-226	2.3 ± 0.1
	U-238	1.6 ± 0.1
	Th-230	1.9 ± 0.1
	Pb-210	2.6 ± 0.2
Southeast		
300	Ra-226	1.1 ± 0.1
600	Ra-226	0.8 ± 0.1
900	Ra-226	1.3 ± 0.1
1200	Ra-226	1.2 ± 0.1
1500	Ra-226	1.1 ± 0.1
	U-238	1.3 ± 0.1
	Th-230	1.5 ± 0.1
	Pb-210	1.3 ± 0.2
North		
300	Ra-226	1.4 ± 0.1
600	Ra-226	1.0 ± 0.1
900	Ra-226	0.7 ± 0.1
1200	Ra-226	1.0 ± 0.1
1500	Ra-226	0.9 ± 0.1
	U-238	1.1 ± 0.1
	Th-230	1.1 ± 0.1
	Pb-210	3.1 ± 0.2
Northeast		
300	Ra-226	1.2 ± 0.1
600	Ra-226	1.0 ± 0.1
900	Ra-226	1.3 ± 0.1
1200	Ra-226	1.0 ± 0.1
1500	Ra-226	1.7 ± 0.1

Table 4.4 Radionuclide concentrations in surface soil samples from Bodo Canyon (Concluded)

Sample direction in meters	Radionuclides	Concentration (pCi/g dry wt[a])
South		
300	Ra-226	1.3 ± 0.1
600	Ra-226	1.1 ± 0.1
900	Ra-226	1.6 ± 0.1
1200	Ra-226	1.4 ± 0.1
1500	Ra-226	0.9 ± 0.1
	U-238	0.8 ± 0.1
	Th-230	1.0 ± 0.1
	Pb-210	1.7 ± 0.2
Southwest		
300	Ra-226	1.0 ± 0.1
600	Ra-226	1.0 ± 0.1
900	Ra-226	1.2 ± 0.1
1200	Ra-226	0.9 ± 0.1
1500	Ra-226	0.9 ± 0.1
West		
300	Ra-226	1.8 ± 0.1
600	Ra-226	1.0 ± 0.1
900	Ra-226	0.9 ± 0.1
1200	Ra-226	1.0 ± 0.1
1500	Ra-226	1.0 ± 0.1
	U-238	0.9 ± 0.1
	Th-230	1.1 ± 0.1
	Pb-210	2.6 ± 0.1
Northwest		
300	Ra-226	1.9 ± 0.1
600	Ra-226	1.2 ± 0.1
900	Ra-226	1.4 ± 0.1
1200	Ra-226	0.9 ± 0.1
1500	Ra-226	0.9 ± 0.1
Site Center	Ra-226	1.2 ± 0.1

[a]The error is twice the counting standard deviation.

NOTE: Sample locations are indicated on Figure 4.1.

Ref. Dames and Moore, 1983b.

Table 4.5 Radionuclide concentrations of subsurface soil samples from Bodo Canyon

Sample direction and depth	Radionuclides	Concentration (pCi/g dry wt[a])
650 meters - Northeast		
0 - 20 cm	U-238	1.3 ± 0.1
	Th-230	1.3 ± 0.1
	Ra-226	0.5 ± 0.1
	Pb-210	1.8 ± 0.2
40 - 60 cm	U-238	1.0 ± 0.1
	Th-230	1.1 ± 0.1
	Ra-226	1.0 ± 0.1
	Pb-210	1.0 ± 0.2
80 - 100 cm	bedrock encountered	
750 meters - Southeast		
0 - 20 cm	U-238	0.8 ± 0.1
	Th-230	1.2 ± 0.1
	Ra-226	1.1 ± 0.1
	Pb-210	1.1 ± 0.1
40 - 60 cm	U-238	1.2 ± 0.1
	Th-230	1.2 ± 0.1
	Ra-226	0.8 ± 0.1
	Pb-210	1.1 ± 0.1
80 - 100 cm	U-238	0.8 ± 0.1
	Th-230	1.0 ± 0.1
	Ra-226	0.7 ± 0.1
	Pb-210	0.9 ± 0.2
1500 meters - Northwest		
0 - 20 cm	U-238	1.0 ± 0.1
	Th-230	1.2 ± 0.1
	Ra-226	1.2 ± 0.1
	Pb-210	2.2 ± 0.1
40 - 60 cm	U-238	0.6 ± 0.1
	Th-230	1.0 ± 0.1
	Ra-226	1.4 ± 0.1
	Pb-210	1.0 ± 0.1
80 - 100 cm	bedrock encountered	

Table 4.5 Radionuclide concentrations of subsurface soil samples from Bodo Canyon (Concluded)

Sample direction and depth	Radionuclides	Concentration (pCi/g dry wt[a])
650 meters - Southwest		
0 - 20 cm	U-238	0.8 ± 0.1
	Th-230	1.1 ± 0.1
	Ra-226	0.8 ± 0.1
	Pb-210	0.8 ± 0.1
40 - 60 cm	U-238	0.9 ± 0.1
	Th-230	0.9 ± 0.1
	Ra-226	0.8 ± 0.1
	Pb-210	0.7 ± 0.1
80 - 100 cm	U-238	0.8 ± 0.1
	Th-230	0.9 ± 0.1
	Ra-226	0.5 ± 0.1
	Pb-210	0.9 ± 0.2
Site center		
0 - 20 cm	U-238	0.9 ± 0.1
	Th-230	1.0 ± 0.1
	Ra-226	1.2 ± 0.2
	Pb-210	0.8 ± 0.1
40 - 60 cm	U-238	0.7 ± 0.1
	Th-230	1.0 ± 0.1
	Ra-226	0.9 ± 0.1
	Pb-210	0.9 ± 0.2
80 - 100 cm	U-238	0.9 ± 0.1
	Th-230	0.9 ± 0.1
	Ra-226	0.5 ± 0.1
	Pb-210	0.8 ± 0.1

[a]The error is twice the counting standard deviation.

NOTE: Sample locations are indicated on Figure 4.1.

Ref. Dames and Moore, 1983b.

Table 4.6 Radionuclide concentrations in sediment samples

Sample location (north, east coordinates)	Sample Number	Radionuclides	Concentration (pCi/g dry wt[a])
53490 N, 51390 E	1	U-238[b]	1.2 ± 0.1
		Th-230	1.3 ± 0.1
		Ra-226	1.0 ± 0.1
		Pb-210	1.2 ± 0.2
54850 N, 52850 E	2	U-238[b]	0.8 ± 0.1
		Th-230	1.0 ± 0.1
		Ra-226	0.5 ± 0.1
		Pb-210	1.2 ± 0.2
56000 N, 60120 E	3	U-238[b]	1.5 ± 0.1
		Th-230	1.6 ± 0.1
		Ra-226	1.9 ± 0.1
		Pb-210	3.6 ± 0.2
55320 N, 60330 E	4	U-238[b]	1.2 ± 0.1
		Th-230	1.4 ± 0.1
		Ra-226	0.7 ± 0.1
		Pb-210	1.3 ± 0.2

[a]The error is twice the counting standard deviation.

[b]Natural uranium as U-238.

NOTE: Sample locations are indicated on Figure 4.1.

Ref. Dames and Moore, 1983b.

Table 4.7 Radionuclide concentrations in vegetation samples

Collection date	Site no.[b]	Radionuclide	Concentration (pCi/kg wet wt.[c])
9/26/81	1	Natural uranium as U-238	11.7 ± 0.6
	2		8.4 ± 0.4
	3		9.3 ± 0.4
6/09/82	1		18.7 ± 0.9
	2		57.0 ± 3
	3		16.3 ± 0.8
8/14/82	1		8.7 ± 0.7
	2		12.7 ± 0.9
	3		185.0 ± 9
9/26/81	1	Th-230	12.[illegible] ± 0.9
	2		7.3 ± 0.6
	3		10.1 ± 0.8
6/09/82	1		17.0 ± 1
	2		16.1 ± 0.8
	3		11.7 ± 0.9
8/14/82	1		11.0 ± 0.7
	2		15.0 ± 1
	3		250.0 ± 10
9/26/82	1	Ra-226	2.0 ± 0.2
	2		3.8 ± 0.3
	3		0.74 ± 0.06
6/09/82	1		29.0 ± 1
	2		23.0 ± 1
	3		34.0 ± 2
8/14/82	1		2.6 ± 0.2
	2		6.0 ± 0.5
	3		250.0 ± 0.9
9/26/82	1	Pb-210	189.0 ± 9
	2		107.0 ± 5
	3		147.0 ± 7
6/09/82	1		260.0 ± 10
	2		320.0 ± 20
	3		76.0 ± 4

Table 4.7 Radionuclide concentrations in vegetation samples (Concluded)

Collection date	Site No.[b]	Radionuclide	Concentration (pCi/kg wet wt.[a])
8/14/82	1		340.0 ± 20
	2		450.0 ± 20
	3		1239.0 ± 60
9/26/81	1	Po-210	67.0 ± 3
	2		74.0 ± 4
	3		1230.0 ± 2
6/09/82	1		165.0 ± 8
	2		97.0 ± 5
	3		46.0 ± 4
8/14/82	1		37.0 ± 2
	2		51.0 ± 2
	3		200.0 ± 10

[a]The error is twice the counting standard deviation.

[b]Site 1 is located about 0.25-mile southwest of the Bodo Canyon Area E site in a Black Sage/Bluegrass community type (Section 1, T34N, R9W). Species collected include: black sage, bluegrass, snakeweed, golden aster, and squirreltail. Approximately one-half of the sample was composed of grass (bluegrass and squirreltail).

Site 2 is located about 0.25-mile east of the Bodo Canyon Area E site in a Black Sage/Western Wheatgrass community type (eastern third section of Section 31, T34 1/2N, R9W). Both black sage and western wheatgrass comprised the bulk of the sample, although rubber rabbitbrush, big sagebrush, and curlycup gumweed were also collected.

Site 3 is located about 0.25-mile northwest of the Bodo Canyon Area E site in a mixed shrub community type (NW 1/4 Section 21, T34 1/2N, R9W). Principal species sampled include skunkbush sumac, gambel oak, pinon, curlycup gumweed, and rubber rabbitbrush.

Ref. Dames and Moore, 1983b.

Table 4.8 Radionuclide concentrations in wildlife collected in Bodo Canyon

Rabbit Number[a]		Radionuclide	Concentration[b] (pCi/kg wet wt.[c])
1		Natural uranium as U-238	0.4 ± 0.2
2			0.3 ± 0.1
3			0.4 ± 0.2
	Average		0.36 ± 0.06[d]
1		Th-230	0.0 ± 0.2
2			0.4 ± 0.2
3			0.4 ± 0.2
	Average		0.27 ± 0.23
1		Ra-226	1.01 ± 0.08
2			0.74 ± 0.07
3			0.50 ± 0.05
	Average		0.75 ± 0.26
1		Po-210	7.0 ± 1
2			2.0 ± 1
3			4.0 ± 1
	Average		4.3 ± 2.5
1		Pb-210	18.0 ± 1
2			14.0 ± 1
3			8.0 ± 1
	Average		13.3 ± 5.0

[a]Three rabbits were trapped within the vicinity of the Bodo Canyon site.
[b]The flesh portion of rabbits was analyzed.
[c]The error is twice the counting standard deviation.
[d]The 0.06 is the standard deviation of 0.4, 0.3, and 0.4.

Ref. Dames and Moore, 1983b.

Table 4.9 Field measurements at Bodo Canyon (October, 1982 - April, 1983)

Location	TLD exposure rate (uR/hr)[a]	Average radon concentration track etch detectors(pCi/l)[b]
BODO CANYON		
Air-particulate location No. 1	23.0 ± 7.0 (2)[c]	0.24 ± 0.05 (6)[c]
Air-particulate location No. 2	19.4 ± 1.0 (3)	0.23 ± 0.04 (6)
Air-particulate location No. 3	23.0 ± 3.9 (3)	0.21 ± 0.03 (6)
REMOTE LOCATIONS		
Air-particulate location No. 4	16.3 ± 0.4 (4)	0.46 ± 0.11 (6)
Air-particulate location No. 5	17.4 ± 1.2 (3)	0.22 ± 0.01 (6)
TRANSPORTATION ROUTE[d]		
A	---	6.3 ± 0.3
B	114 ± 13	10.1 ± 1.3
C	---	3.6 ± 0.3
D	24.2 ± 2.5	0.79 ± 0.02
E	20.9 ± 1.5	0.56 ± 0.08
F	13.2 ± 0.6	---
G	15.6 ± 1.3	---

[a] The error is one counting standard deviation.
[b] The error is twice the track counting standard deviation.
[c] Number in parentheses is the number of detector measurements on which the quoted mean and standard deviation are based. Each TLD detector consisted of two chips that were read individually and averaged to yield one measurement value.
[d] Each value listed for locations along the transportation route is based on eight TLD or three radon detector readings.

NOTE: Detector locations are indicated on Figures 4.1 and 4.3.

Ref. ANL, 1983.

5.0 GROUND-WATER HYDROLOGY

5.1 GROUND-WATER REGIME

The Bodo Canyon disposal site is located in an area of regional ground-water recharge. The site is underlain by unconsolidated alluvial and colluvium soils above fractured and weathered bedrock. The surficial materials at the Bodo Canyon site consist primarily of sandy and silty clay. The soil overburden varies in thickness across the site from about 1.0 at the drainage divides to 65 feet in the center of the site. The alluvial and colluvium materials are in turn underlain by a zone of fractured and weathered bedrock about 5 to 35 feet thick. The bedrock consists of the Cliff House Sandstone Unit of the Mesa Verde Group, which are sedimentary strata of Mesozoic age (see Figure 7.2 in Section 7.0).

The Bodo Canyon area appears to be a recharge area. However, recharge rates are restricted by the surficial clay-rich soils. There is a shallow water-table system about 20 to 30 feet below the surface, which rests within surficial alluvium and the fractured shale zone of the Cliff House Unit, above the less permeable, unweathered sandy shale bedrock. Flow directions within this system are aligned similarly with the surface topographic gradients in the immediate area. Small amounts of infiltrating water migrate through the surficial overburden soils and weathered bedrock, move toward the Animas River, and eventually discharge in that vicinity.

Ground water also occurs within sandstone lenses of the Cliff House Sandstone and within coal seams of the Menefee Formations (D&M, 1984). Flow appears to be to the northeast toward the northern drainage of Bodo Canyon in accordance with the topography. Recharge to these lenses is from direct infiltration of precipitation and surface runoff in outcrop areas and possible leakage from the overlying unconfined water-table system. Potential aquifers located 300 to 400 feet beneath the site in the Point Lookout Sandstone may be partially recharged by leakage from the overlying water-bearing strata. Ground-water flow in these deeper aquifers is controlled by regional pressure gradients as well as structural and stratigraphic factors. The ground water in this deeper regime flows along the dip of the more permeable beds and formations towards the center of the San Juan Basin which is southeast of the site.

Twelve potentiometers were installed by Dames & Moore (D&M) at the Bodo Canyon site (Figure 5.1). The potentiometers ranged in depth from approximately 33 to 200 feet below the ground surface. Some were used for monitoring water levels and taking samples from the soil overburden and weathered bedrock interval while others were for the deeper saturated zones in the unweathered bedrock. Well completion information is presented in Table 5.1.

The Technical Assistance Contractor (TAC) drilled four additional boreholes at Bodo Canyon, completing two as shallow monitoring wells (45 and 52 feet deep), and two as deep wells tapping the Menefee Formation (192 and 255 feet deep). The deep wells have been core sampled and hydraulically tested using double packers. Quarterly water-quality sampling of

the wells was initiated in January, 1985. Monthly water-level measurements in the four wells were also initiated at the time (Table 5.3).

Figure 5.2 shows the approximate locations of the four TAC wells at the Bodo Canyon site. Well completion information is presented in Table 5.2. Sandy shale bedrock of the Cliff House Sandstone was encountered at depths of 52 and 42 feet during drilling at the site. Thin layers of fine-grained sandstone were noted in the upper 50 feet of this formation. Beginning at depths greater than 145 feet, in the Menefee Formation, coal seams from one inch to 6.5 feet thick occur in the sandy shale. Packer testing of intervals containing these coal beds yielded the highest flow "takes," indicating zones of higher permeability within the Menefee Formation.

Hydraulic conductivity values determined from packer test data ranged from 0.03 feet per day (1.1×10^5 cm/sec) in the upper bedrock surface (50 to 55 feet deep) to 0.0032 feet per day (1.1×10^6 cm/sec) in competent shale (105 to 125 feet deep) to as high as 1.39 feet per day (4.9×10^4 cm/sec) in a six-foot coal seam approximately 180 feet deep. These values vary over almost three orders of magnitude, and are consistent with values reported by Dames & Moore in the 1984 draft EIS for the Durango site. The method used to calculate conductivity values is derived from the Department of Interior's Ground Water Manual, Chapter X (1981). Table 5.3 presents a summary of field data obtained from packer testing, slug testing, and water-level monitoring of the four TAC wells at Bodo Canyon. This table also includes field chemistry parameters from initial water

sampling of these wells. Table 5.4 presents the results of water-quality analyses performed on ground-water samples collected from the TAC wells in January, 1985.

Static ground-water levels at the Bodo Canyon site were monitored by Dames and Moore in their wells from October 29, 1982, to June 8, 1983. The water-level data obtained during the above monitoring period are tabulated in Table 5.5. A contour map of the potentiometric surface in the bedrock for June 8, 1983, is presented in Figure 5.3.

As shown in Table 5.5, the elevation of the static ground-water table in the D&M wells fluctuated significantly over the site during the nine-month monitoring period. The minimum depth of the water table below the ground surface was recorded in Boring SW-1 (18.7 feet) at the north-central part of the site. A maximum depth of 76.1 feet was measured in Boring B-1 which is also in the north-central part of the site. The large fluctuations in the water-table levels that were measured during the monitoring period indicate that the recharge of the water-table system is both localized and seasonal. Ground-water flow rates within this unconfined system will therefore vary seasonally.

The hydraulic conductivity values of the soil overburden materials beneath the Bodo Canyon site range from about 2.8×10^{-4} to 0.43 feet per day. Hydraulic conductivity values for the fractured and weathered zone of the bedrock range from 0.2 to 5.6 feet per day and for the massive bedrock formation range from 2.8×10^{-4} to 0.43 feet per day which is

consistent with the overburden soils. In the bedrock, the conductivity is almost entirely controlled by fracturing oblique to the bedding planes (D&M, 1983b).

5.2 GROUND-WATER QUALITY

Ground-water samples were collected from seven D&M potentiometers in November, 1982, and March, May, and August, 1983. These samples were analyzed for major cations and anions, metals, and radiochemistry. The analytical results for each of the samples were compared with the EPA recommended primary and secondary drinking water standards.

Ground water within the unconsolidated overburden is classified as a calcium-sulfate type, with total dissolved solids ranging from 350 to 1800 milligrams per liter. The concentrations of $CaCO_3$ are all greater than 180 milligrams per liter, indicating the water is very hard. Concentrations of sulfate, total dissolved solids, hexavalent chromium, total iron, total lead, total manganese, gross alpha, and combined Ra-226 and Ra-228 exceed state or Federal drinking water standards (Table 5.6) (Dames and Moore, 1983b).

Ground-water samples from the Menefee Formation and Cliff House Sandstone indicate that the water is generally a sodium-bicarbonate type and very hard (greater than 180 milligrams of $CaCO_3$ per liter). Total dissolved solids concentrations range from 676 to 1540 milligrams per liter. Constituents that exceed state or Federal drinking water standards include

sulfate, total dissolved solids, ammonia, total iron, total manganese, total lead, total barium, hexavalent chromium, combined Ra-226 and Ra-228, gross alpha, and gross beta (Table 5.7).

5.3 GROUND-WATER USE

Three domestic and stock-watering water wells, have been identified within a one-mile radius of the Bodo Canyon site (Figure 5.4). Information about these wells is listed in Table 5.8. The four wells and eight piezometers installed by Dames and Moore were plugged and abandoned. Four monitoring wells were installed in Bodo Canyon by the TAC in November and December, 1984, and will be used for water-level measurements and water-quality sampling through summer 1985. Upon completion of the monitoring program, the wells will be plugged and abandoned in accordance with the regulations of the Colorado Division of Water Resources and the site access agreement.

5.4 DATA EVALUATION

The existing data supplemented by the ongoing data collection program are adequate to define the ground-water regime and establish the impact of any infiltration through the stabilized embankment into the shallow ground-water system. These data also indicate that there should be no need for dewatering during construction. A source of water for construction will be identified by the Remedial Action Contractor.

5.5 ONGOING DATA COLLECTION

To supplement the ground water and level information collected by Dames and Moore, monthly water-level measurement and quarterly water-quality sampling and analysis will continue at the four TAC wells through the summer of 1985.

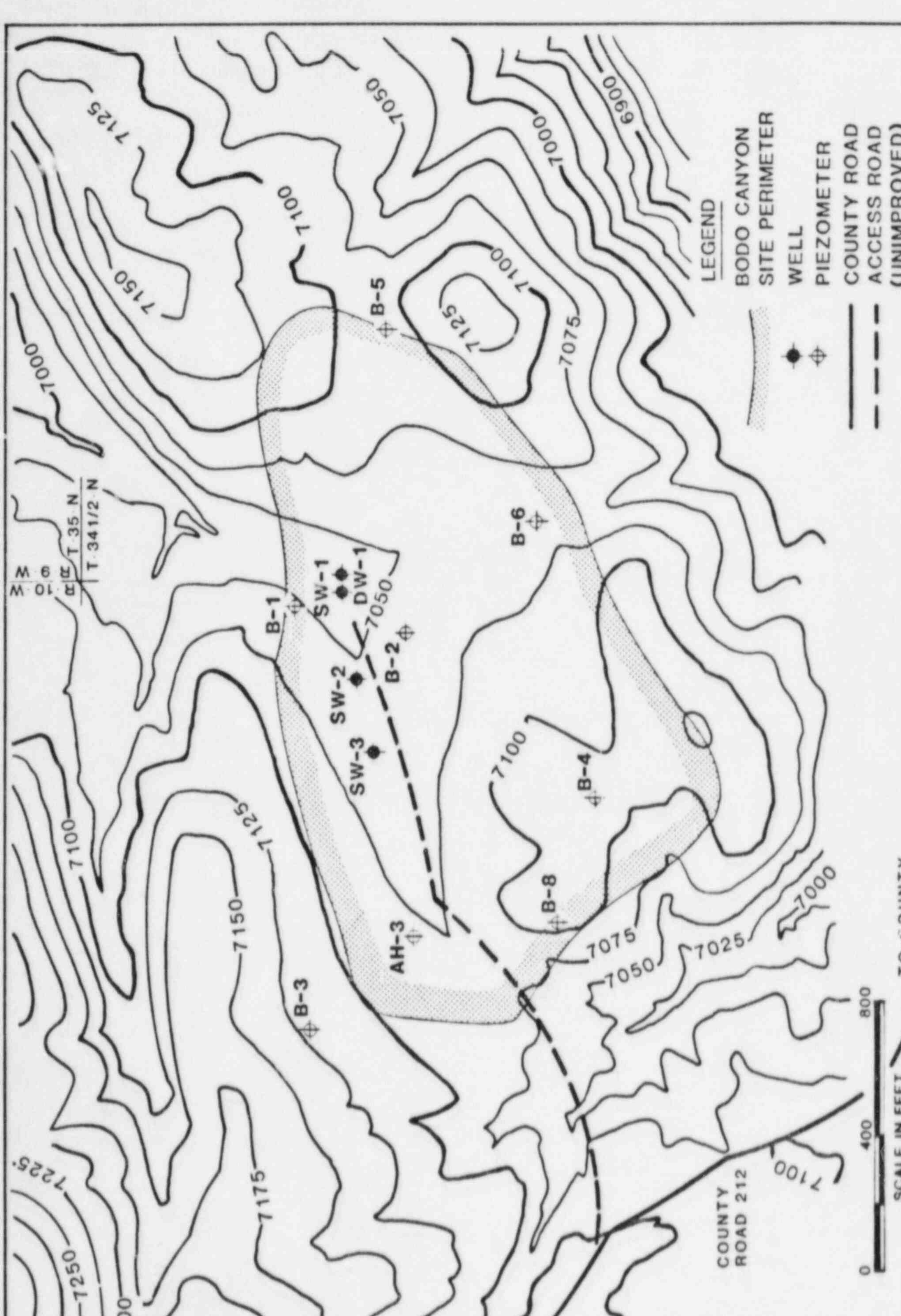


FIGURE 5.1
LOCATION OF D&M WELLS AND PIEZOMETERS

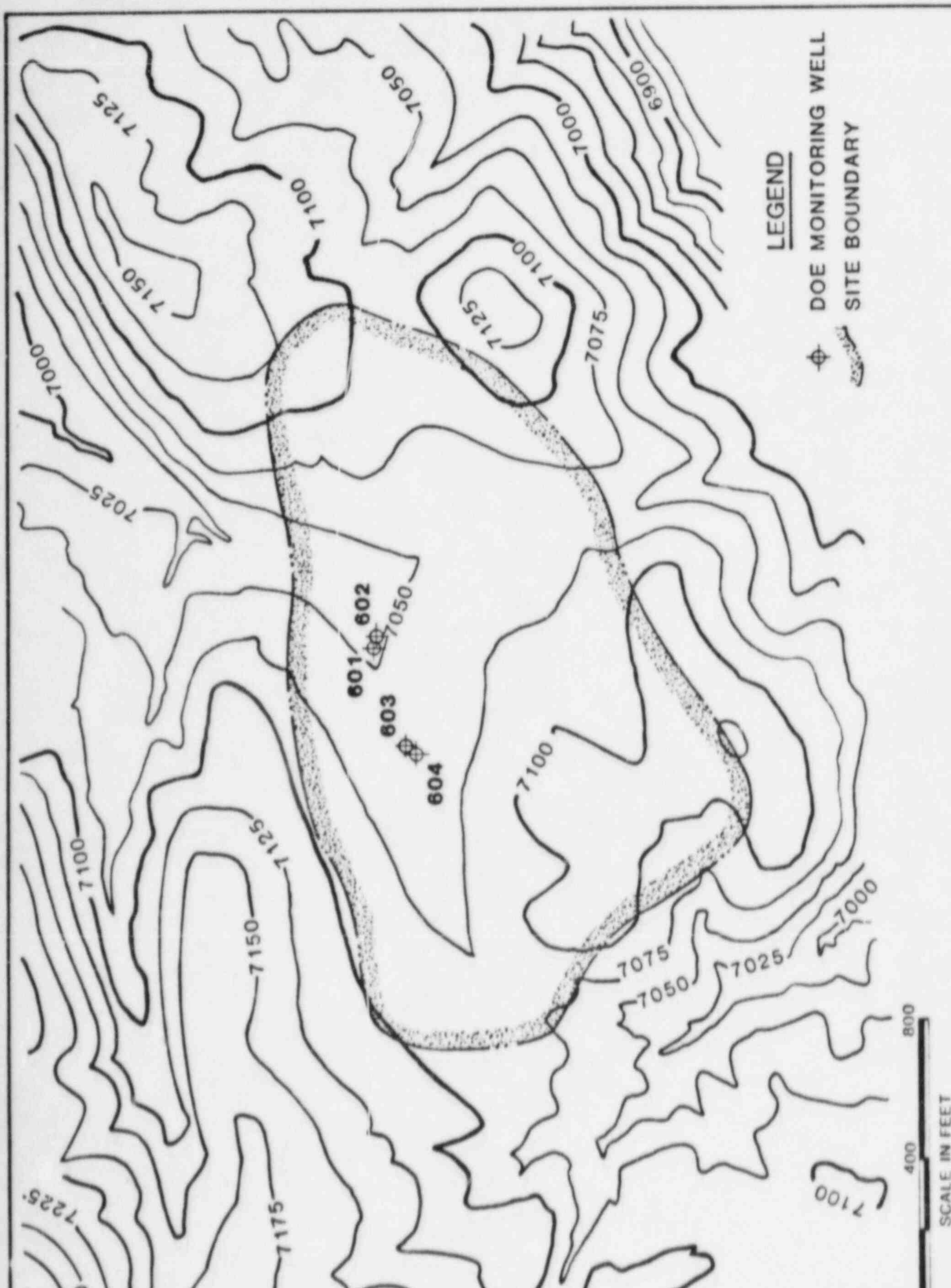


FIGURE 5.2
LOCATION OF TAC MONITORING WELLS AT BODO CANYON (DUR03)

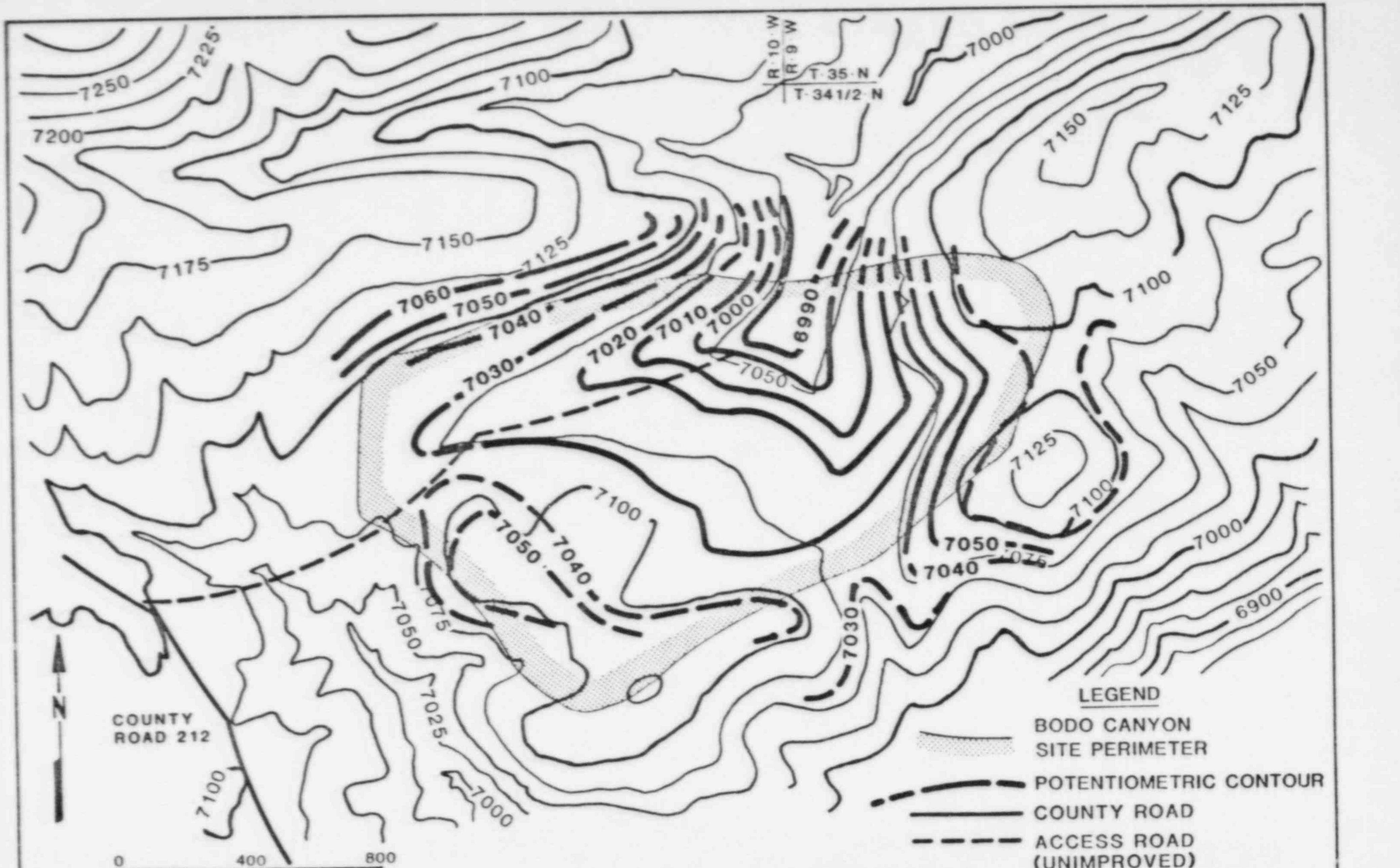


FIGURE 5.3
POTENTIOMETRIC SURFACE FOR THE CLIFF HOUSE AQUIFER
BODO CANYON SITE JUNE 8, 1983

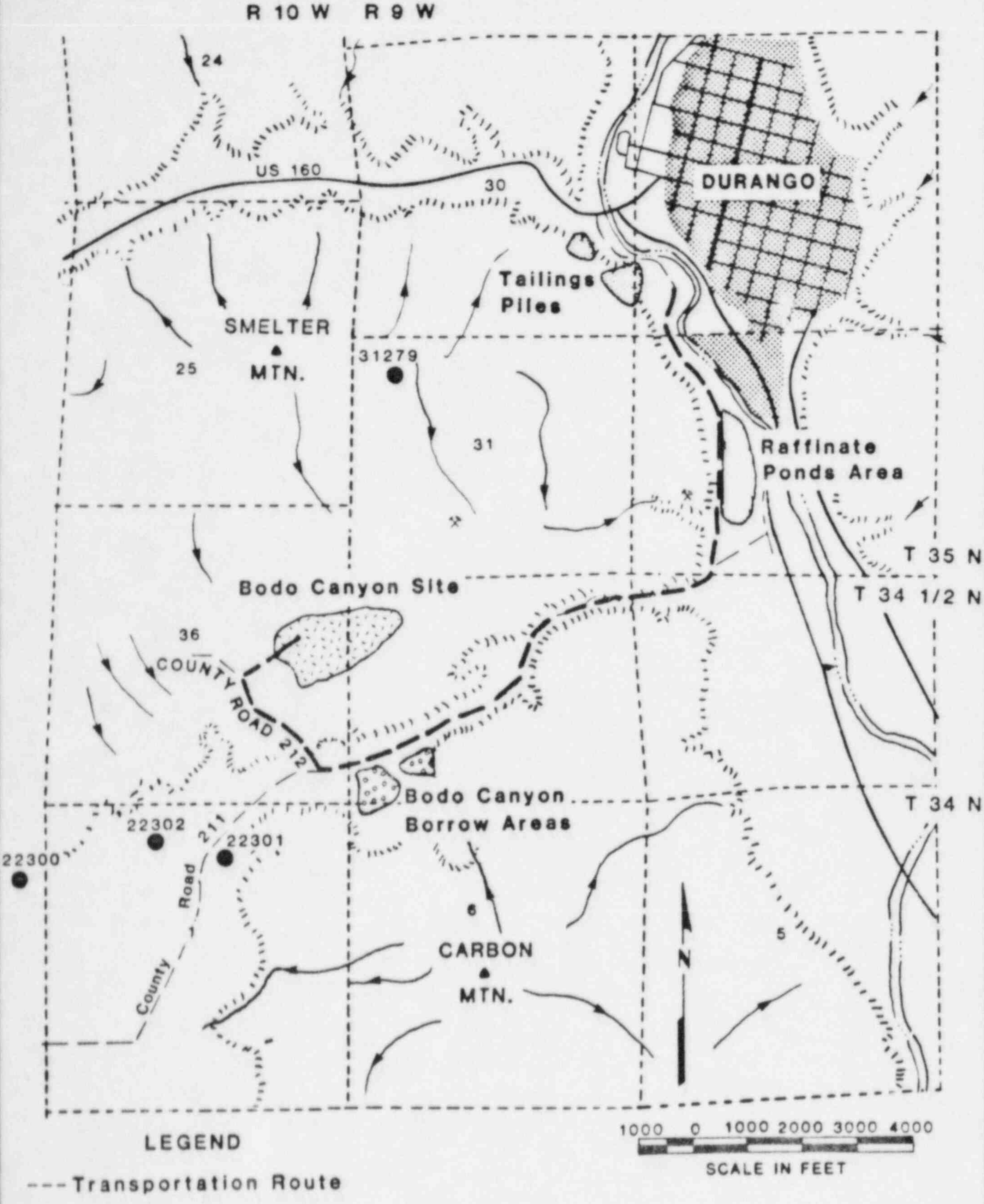


FIGURE 5.4
LOCATIONS OF WATER WELLS IN
BODO CANYON AREA

Table 5.1 D&M monitoring well and piezometer details, Bodo Canyon

Identification number[a]	Date drilled	Location		PVC				
		Northing	Easting	Elevation (top of casing)	Total depth of borehole (ft)	Casing diameter (inches)	Blank interval (ft)	Slotted interval (ft)
Well								
SW-1	10/29/82	54391.63	52622.45	7042.12	44.0	4	0.67-13.5	13.5-44.0
SW-2	11/04/82	54338.29	52362.97	7053.69	64.0	4	0.50-33.8	33.8-64.0
SW-3	11/04/82	54281.91	52128.35	7062.88	69.5	4	0.70-38.9	38.9-69.0
DW-1	11/02/82	54407.42	52659.76	7041.14	200.0	4	0.00-62.0	62.0-192.0
Piezometer								
AH-3	10/28/82	54148.39	51588.00	7077.17	33.0	2	0.00-23.0	23.0-33.0
B-1	10/15/82	54513.31	52597.70	7049.82	84.5	2	0.00-69.5	69.5-84.5
B-2	10/21/82	54181.26	52541.57	7055.89	93.5	2	0.15-73.5	73.5-93.5
B-3	10/22/82	54459.32	51346.24	7115.96	63.0	2	0.00-43.0	43.0-63.0
B-4	10/18/82	53650.59	52024.81	7107.24	122.8	2	0.25-102.8	102.8-122.8
B-5	10/19/82	54251.39	53441.60	7094.70	121.0	2	0.00-101.0	101.0-121.0
B-6	10/24/82	53822.25	52843.79	7068.10	100.0	2	0.60-85.0	85.0-100.0
B-8	11/06/82	53772.95	51648.58	7106.69	40.0	2	0.00-25.8	25.8-40.0

Table 5.1 D&M monitoring well and piezometer details, Bodo Canyon (Concluded)

I.D. number[a]	Gravel pack interval (ft)	Bentonite interval (ft)	Clay backfill interval (ft)	Cement grout interval (ft)	Steel casing stickup (feet above ground surface)	PVC casing stickup (feet above ground surface)	Interval screened or packed
<u>Well</u>							
SW-1	10.5-44.0	7.5-8.5	3.0-7.5 8.5-10.5	0.0-3.0	0.85	0.67	Colluvium
SW-2	6.5-64.0	2.3-4.3	1.5-2.3 4.3-6.5	0.0-1.5	0.65	0.50	Colluvium
SW-3	9.0-69.5	5.2-7.4	1.7-5.2 7.4-9.0	0.0-1.7	1.80	1.70	Colluvium
DW-1	47.5-200.0	40.3-42.5	2.0-40.3 42.5-47.5	0.0-2.0	1.15	1.00	Bedrock
<u>Piezometer</u>							
AH-3	20.0-33.0	11.0-13.0	0.0-11.0 13.0-20.0	None	None	0.00	Colluvium
B-1	68.0-84.5	None	0.0-65.0	65.0-68.0	None	0.00	Bedrock
B-2	72.0-93.5	69.0-72.0	0.0-69.0	None	None	2.15	Bedrock
B-3	42.0-63.0	39.0-42.0	0.0-39.0	None	None	0.00	Bedrock
B-4	101.0-122.8	98.0-101.0	0.0-98.0	None	None	0.25	Deep bedrock
B-5	100.0-121.0	97.0-100.0	0.0-97.0	None	None	0.00	Deep bedrock
B-6	84.0-100.0	81.0-84.0	0.0-81.0	None	None	2.60	Bedrock
B-8	24.0-40.0	21.0-24.0	0.0-21.0	None	None	0.00	Bedrock

[a]For monitoring well and piezometer locations, see Figure 5.1

Ref. Dames and Moore, 1983b.

Table 5.2 Well Construction Data for Bodo Canyon TAC Monitoring Wells[a]

Well ID (date installed)	Location	Total depth (ft)	Slotted interval	Formation screened	Elevation (t.o.c.)[b]
DUR03-601 (11/15/84)	N 42,330.18 E 46,122.05	52.0	39.5-49.5 ft. below sfc	alluvium @ top of bedrock	7049.91
DUR03-602 (11/30/84)	N 42,314.78 E 46,128.02	192.0	165-180 ft. below sfc	Menefee shale with coal seams	7048.68
DUR03-603 (1/6/85)	N 42,243.18 E 45, 815.34	198.0	165-195 ft. below sfc	Menefee shale with coal seams	7062.81
DUR03-604 (12/2/84)	N 42,239.00 E 45,798.98	45.0	32.0-42.0 ft. below sfc	alluvium on top of shale	7064.15

[a]All wells constructed of 2-inch diameter, Schedule 40 PVC.

[b]Elevation surveyed at top of casing (t.o.c.). In feet above MSL.

Table 5.3 Summary of Preliminary field data from TAC wells at Bodo Canyon (DUR03)

Well ID number	Packer test results (horizontal K)	Slug test results[a] (horizontal K)	Field chemistry[b]	Depth to water (ft below top of well casing)			
				1/24/85	2/17/85	3/14/85	4/15/85
601 screened 39.5-49.5' alluvium	Not tested	sandy silt alluvium 1.32 ft/day (4.7 x 10^{-4} cm/sec) (Hvorslev) 1.19 ft/day (4.2 x 10^{-4} cm/sec) (Bouwer-Rice)	pH = 7.59 T = 8.0°C Cond = 2510 mhos Alk = 372 mg/l	35.02	35.0	33.66	26.8'
602 screened 165-180'	range: 0.008-0.40 ft/day min: 120-125 ft (shale) max: 180-185 ft (coal) top of bedrock: 0.11 ft/day (62-68 ft)	shale with coal seams 0.36 ft/day (Cooper et al.)	pH = 7.47 T = 8.9°C Cond = 3250 mhos Alk = 374 mg/l	72.91	73.17	72.83	67.9'
603 screened 165-195'	0.0032-1.39 ft/day min: 120-125 ft (shale) max: 180-185 ft (coal) top of shale: 0.032 ft/day (50-55 ft)	shale with coal seams 0.3 ft/day (Cooper et al.)	pH = 7.16 T = 10.5°C Cond = 4320 mhos Alk = 381 mg/l	87.34	88.08	87.92	93.8'
604 screened 32-43' alluvium	Not tested	dry	dry	dry	dry	dry	dry

[a]Slug test data analyzed by methods referenced.
[b]Alkalinity measured as mg/l $CaCO_3$ at pH = 4.5.

Table 5.4 Water-quality data from TAC monitoring wells at Bodo Canyon[a] (sampling dates: January 23-24, 1985)

Well and sample number	Results (all concentrations in mg/l; radionuclides in pCi/l)														
	Cl	SO_4	Na	K	Mg	Ca	B	F	NH_4	NO_3	Si	PO_4	Br	Al	Sb
601-01 (alluvium)	35	1200[c]	106	2.36	159	307	0.02	0.28	0.1	<1	6.3	<0.15	--	<0.1	<0.003
601-02 (split) screened 40-50' in sandy silt	36	1200[c]	100	2.3	159	302	0.02	0.29	0.2	<1	6.1	<0.15	--	<0.1	<0.003
602-01 (Menefee) 165-180' shale and coal	12	1700[c]	167	6.98	258	312	0.07	0.26	1.9	<1	7.9	<0.15	--	<0.1	<0.003
603-01[b] (Menefee) 165-195' shale and coal	11.5	2800[c]	106	10.1	424	550	0.06	0.30	3.4	<1	12.7	<0.15	--	<0.1	<0.003

Table 5.4 Water quality data from TAC monitoring wells at Bodo Canyon[a]
(Sampling dates: January 23-24, 1985) (Continued)

Well and sample number	Results (all concentrations in mg/l; radionuclides in pCi/l)														
	As	Ba	Cd	Cr	Co	Cond	Alk	Cu	Fe	Pb	Mn	Hg	Mo	Ni	Se
601-01 (alluvium)	<0.01	<0.01	<0.001	<0.01	<0.05	2510	372	<0.02	0.14	<0.01	0.20[c]	<0.0002	<0.01	<0.04	<0.005
601-02 (split) screened 40-50' in sandy silt	<0.01	<0.01	<0.001	<0.01	<0.05	2510	372	<0.02	0.11	<0.01	0.18[c]	<0.0002	<0.01	<0.04	0.007
602-01 (Menefee) 165-180' shale and coal	<0.01	<0.01	<0.001	<0.01	<0.05	3250	374	<0.02	10.4[c]	<0.01	0.90[c]	<0.0004	<0.01	<0.04	<0.005
603-01[b] (Menefee) 165-195' shale and coal	<0.01	<0.01	0.001	<0.01	<0.05	4320	381	<0.02	2.25[c]	<0.01	0.52[c]	<0.0002	<0.01	<0.04	<0.005

Table 5.4 Water quality data from TAC monitoring wells at Bodo Canyon[a] (Sampling dates: January 23-24, 1985) (Concluded)

Well and sample number	Results (all concentrations in mg/l; radionuclides in pCi/l)													
	Ag	Sr	Sn	V	Zn	TDS	U-238	U-234	Po-210	Pb-210	Ra-226	Ra-228	Th-230	Field pH
601-01 (alluvium)	<0.1	1.3	<0.005	<0.01	0.191	2180[c]	2	5	<1	<1.5	<1	--	<1	7.59
601-02 (split) screened 40-50' in sandy silt	<0.1	1.4	<0.005	<0.01	0.190	2140[c]	2	5	<1	<1.5	<1	--	<1	7.59
602-01 (Menefee) 165-180' shale and coal	<0.1	3.6	<0.005	<0.01	0.187	2980[c]	<1	<1	<1	<1.5	<1	--	<1	7.47
603-01[b] (Menefee) 165-195' shale and coal	<0.1	12.2	<0.005	<0.01	0.182	4580[c]	<1	<1	<1	<1.5	<1	--	<1	7.16

[a]Analytical lab: Bendix Field Engineering Corporation, Grand Junction, Colorado.
[b]Average of two duplicate values.
[c]Exceed Federal secondary MCL's for drinking water.

Table 5.5 O&M Water-level information, Bodo Canyon Area E[a]

Sampling date	B-1	B-2	B-3	B-4	B-5	B-6	B-8	SW-1	SW-2	SW-3	DW-1	AH-3
10/29/82	43.5	40.4	31.4	28.6	34.4	42.0	NM	27.8	NM	55.3	NM	Dry
10/30/82	NM	NM	NM	NM	NM	NM	NM	NM	NM	47.0	NM	Dry
11/01/82	43.5[b]	40.4	31.4	28.9[b]	34.7	42.0[b]	NM	27.8	NM	46.5	NM	Dry
11/03/82	52.9	40.6	31.4	42.8	34.8	40.5	NM	28.1[b]	NM	46.5	46.0[b]	Dry
11/04/82	NM	NM	NM	NM	NM	NM	NM	28.1	NM	46.4	48.0	NM
11/05/82	NM	NM	NM	NM	NM	NM	NM	NM	39.6[b]	48.9[b]	53.2	NM
12/16/82	64.0	---	---	NM	---	---	NM	NM	NM	NM	NM	NM
02/15/83	NM	NM	NM	NM	NM	NM	NM	NM	65.0	68.0	---	NM
02/24/83	NM	NM	NM	NM	NM	NM	NM	33.0	53.0	68.0	58.0	NM
03/02/83	67.0	41.0	34.0	NM	35.0	42.0	NM	31.0	64.0	52.0	58.0	33.0
03/09/83	65.7	40.6	64.1	70.0	33.4	41.9	33.9	43.9	42.6	50.8	58.3	34.9
03/13/83	NM	NM	NM	NM	NM	NM	NM	30.6[b]	42.3[b]	50.5[b]	58.9[b]	NM
03/16/83	76.1	39.3	32.3	70.0	32.8	40.8	33.5	28.6	41.1	50.2	58.3	Dry
03/23/83	67.2	42.6	32.2	69.3	31.4	40.9	32.8	28.5	41.2	50.2	58.3	33.7
03/27/83	66.1[b]	NM	32.1[b]	NM	NM	40.9[b]	NM	NM	NM	NM	NM	NM
03/30/83	75.3	42.9	44.9	68.8	30.2	63.1	28.5	24.3	41.1	49.7	58.2	Dry
04/06/83	73.9	44.1	48.3	68.6	29.9	41.0	38.2	22.7	40.3	49.8	59.1	Dry
04/13/83	72.6	45.0	54.6	67.5	28.7	40.2	39.2	19.2	39.6	49.0	64.8	Dry
04/19/83	62.6	44.8	54.2	67.8	27.7	39.9	35.2	18.7	38.2	48.4	54.2	Dry
04/26/83	61.0	34.1	54.0	66.3	26.9	39.8	36.2	19.6	38.4	48.1	54.4	Dry
05/10/83	60.6	34.9	54.1	66.5	27.0	39.4	36.2	20.3	38.4	47.4	54.1	Dry
05/17/83	60.2	34.6	54.0	68.0	28.3	39.1	36.2	21.7	36.9	47.1	53.2	Dry
05/25/83	60.2	34.6	54.0	68.1	27.9	38.7	37.3	22.2	37.0	46.4	53.2	Dry
06/01/83	NM	NM	54.1[b]	NM	NM	38.3[b]	NM	23.2[b]	36.7[b]	46.0[b]	53.1[b]	NM
06/08/83	62.3	34.9	54.0	65.3	28.4	37.9	Dry	23.5	37.1	46.7	53.8	Dry

[a]For well and piezometer locations, see Figures 5.1 and 5.2.
[b]Indicates well was bailed after water-level measurement.

Ref. Dames and Moore, 1983b

NOTES:
All measurements in feet below top of casing.
NM indicates not measured.
--- indicates measurement determined to be invalid.

Table 5.6 List of parameters which exceed state or Federal drinking water standards, alluvial and colluvial aquifer, Bodo Canyon Area E

Parameter	Federal standard[b]	State standard	Date sampled	Well number[a]		
				SW-1	SW-2	SW-3
Total iron	0.3[b]	0.3	11/05/82	69	56	100
			03/13/83		13.0	4.76
Total lead	0.05	0.05	11/05/82	0.06	0.05	0.06
			03/13/83			
Total manganese	0.05	0.05	11/05/82	1.25	0.95	1.33
			03/13/83		1.05	0.20
Total chromium (hexavalent)	0.05	0.05	11/05/82	0.08	0.06	0.10
Total barium	1.0	1.0	11/05/82	1.0	0.8	0.9
Total dissolved solids	500	500	11/05/82	856	1776	994
			03/13/83		1646	1028
Total sulfate	250	c	11/05/82	398	971	413
			03/13/83		889	435
Sulfate	c	250	11/05/82	352	939	405
			03/13/83		872	436
Radium 226-228 combined (total)	5.0	c	11/05/82	8.7± 4.0	8.0± 4.0	7.2± 4.0
			03/13/83			
Gross alpha (total)	15.0	c	11/05/82	29.1±23.1	15.9±19.9	7.8±17.9
			03/13/83		19.7±11.9	0.0± 5.6

[a]For well locations see Figure 5.1.
[b]All values reported on a dissolved basis in milligrams per liter, unless otherwise noted.
[c]Value not determined.

Ref. Dames and Moore, 1983b.

NOTE: Reported values for total combined radium and gross alpha in picocuries per liter.

Table 5.7 List of parameters which exceed State or Federal drinking water standards, bedrock aquifer, Bodo Canyon Area E

Parameter	Federal standard	State standard	Date sampled	Well number[a] B-1	B-2	B-3	DW-1
Total iron	0.3	0.3	11/05/82	NS	NS	NS	1.01
			03/13/83	NS	NS	NS	
			03/23 & 27/83	590	43	65	NS
Total lead	0.05	0.05	03/13/83	NS	NS	NS	
			03/23 & 27/83	1.15	0.51	0.25	NS
Total manganese	0.05	0.05	11/05/82	NS	NS	NS	0.65
			03/13/83	NS	NS	NS	
			03/23 & 27/83	3.94	0.27	0.77	NS
Total chromium (hexavalent)	0.05	0.05	03/13/83	NS	NS	NS	
			03/23 & 27/83	0.29	0.05	0.06	NS
Total barium	1.0	1.0	03/23 & 27/83	11.9	0.6	1.5	NS
Total dissolved solids	500	500	11/05/82	NS	NS	NS	1168
			03/13/83	NS	NS	NS	
			03/23 & 27/83	896	676	1540	NS
Total sulfate	250	---	11/05/82	NS	NS	NS	254
			03/13/83	NS	NS	NS	
			03/23 & 27/83	320	82	751	NS
Sulfate	---	250	11/05/82	NS	NS	NS	249
			03/13/83	NS	NS	NS	
			03/23 & 27/83	264	82	721	NS
Ammonia	---	0.5	11/05/82	NS	NS	NS	0.56
Radium 226-228 combined (total)	5.0	---	11/05/82	NS	NS	NS	6.3±4.1
			03/13/83	NS	NS	NS	
			03/23 & 27/83	59.8± 6.8	10.9± 5.0	16.2± 5.9	NS
Radium 226-228 combined	5.0	---	03/23 & 27/83	2.0± 2.3	5.1± 2.6	4.2± 2.8	NS
Gross alpha (total)	15.0	---	03/13/83	NS	NS	NS	
			03/23 & 27/83	336.5±184.2	43.5±24.6	7.0±29.1	NS
Gross beta (total)	50.0	---	03/13/83	NS	NS	NS	
			03/23 & 27/83	514.5±419.9	0.0±63.1	121.6±85.6	NS

[a]For well locations see Figures 5.1 and 5.2.

Ref. Dames and Moore, 1983b.

NOTES:
All values reported on a dissolved basis in milligrams per liter, unless otherwise noted.
NS indicates not sampled.
--- indicates value not determined.
Reported values for combined radium, gross alpha, and gross beta in picocuries per liter.

Table 5.8 Records of selected water wells in the Bodo Canyon area

State of Colorado well permit number	Location	Owner/User name and address	Year drilled	Total depth of well (ft)	Casing diameter (in)	Ground elevation (ft)	Depth to water (feet below land surface)	Pump test date
22300	T.34N.R.10W. SE NE Sec.2	M. L. Bodo Durango, CO	1916	185	5	NA	NA	NA
22301	T.34N.R.10W. NW NE Sec.1	M. L. Bodo Durango, CO	1900	185	4	NA	NA	NA
22302	T.34N.R.10W. NE NW Sec.1	M. L. Bodo Durango, CO	1949	88	7	6700	30	1964

NOTES:

Data obtained from the State of Colorado Office of the State Engineer, June, 1981.
NA indicates data not available.

Ref. Dames and Moore, 1981b.

6.0 SURFACE-WATER HYDROLOGY

6.1 GENERAL

The Bodo Canyon site is located in the foothills of the San Juan Mountains on the west slope of Smelter Mountain. It is in a broad canyon between Smelter Mountain and Carbon Mountain which is typified by ravines, gullies, and box canyons which are well defined with steep side slopes and gradients up to 20 percent. The main Bodo Canyon drainage flows east to the Animas River just to the north of the disposal site. It is an ephemeral stream that will contain some flow from April through July and is subject to large fluctuations of flow caused by the intense thunderstorm events which occur in the Southwest.

6.2 DESCRIPTION OF WATERSHED

There are four drainage basins that impact the Bodo Canyon site. The two larger drainages are to the north, one is to the south, and one is the disposal site which is a small basin that drains to the north (Figure 6.1). The four drainages have a combined area of about 285 acres. The north drainages have a drainage area of about 170 acres. The south drainage basin covers about 75 acres while the disposal site drainage covers about 40 acres. A small coffer dam has been constructed across the disposal site drainage and usually contains small amounts of water. Vegetative

cover in the area is good, averaging about 90 percent. The area had been overgrazed and was showing evidence of severe erosion; however, it has been stabilized over the past ten years.

6.3 HISTORICAL FLOODS

No data on historical floods are available for either the Bodo Canyon disposal site or the portion of the transportation corridor that is in Bodo Canyon. For the three subwatersheds around the Bodo Canyon site, floods of various recurrence intervals were calculated by synthetic methods since no flood records are available (Dames and Moore, 1983a). The synthetic method used was the Soil Conservation Service rainfall excess-unit hydrograph method with the actual computations performed using the computer program HEC-1, Dam Safety Version, from the Hydrologic Engineering Center (1981). Hydrographs were calculated for the Probable Maximum Flood (PMF) that would result from a 6-hour local Probable Maximum Precipitation (PMP).

The 6-hour local PMP for these areas is estimated to be 10.7 inches (U.S. Department of Commerce, 1977). The distribution of the 6-hour local PMP for these areas into 5-minute incremental and accumulative values is shown in Table 6.1. The PMF hydrographs for the first two subwatersheds were combined to obtain a PMF peak of 3845 cfs for the total drainage area of 170 acres. The PMF for the third watershed is estimated to be 1740 cfs. A summary of the hydrographs for each subwatershed is given in Table 6.2.

Uniform-flow computations using an approximate cross section of the stream flowing west to east on the north side of the Bodo Canyon disposal site with an average channel slope of 0.12 foot per foot and Manning's "n" factor of 0.04, indicated that the water-surface elevation corresponding to the PMF peak of 3845 cfs for this watershed would be about 7039 feet. The corresponding channel velocity is estimated to be 17 feet per second. Similar computations for the stream flowing from the northwest to the southeast on the west side of the tailings disposal site with an average channel slope of 0.10 foot per foot and Manning's "n" factor of 0.04, indicated that the water-surface elevation corresponding to the PMF peak of 1740 cfs would be about 7002 feet. The corresponding channel velocity is estimated to be 19 feet per second.

6.4 SURFACE-WATER QUALITY

Monthly surface-water samples were collected for a 1-year period from four sampling locations in the Bodo Canyon area (Figure 6.2). Two sites are located in the canyon's main drainage channel and two in the drainage channel to the north of Bodo Canyon, herein referred to as "north drainage."

On the ephemeral north drainage channel, the first sampling location (Site 6) is located in the head of the canyon near the cofier dam in the disposal area and the other location (Site 3) is approximately 150 yards upgradient from the confluence of the north drainage and the Animas River.

These two sites were to be sampled monthly over a period of 1 year; however, they were sampled only twice since sufficient flow for sampling did not exist for most of the year. The water samples were collected on March 23 and 24, 1982, and February 22, 1983. Parameters that exceeded either state or Federal drinking water standards included sulfate, total dissolved solids, total iron, total manganese, total lead, total mercury, gross alpha, and combined Ra-226 and Ra-228 (Table 6.3).

The surface water from the north drainage is classified as magnesium sulfate type. The water is very hard (greater than 180 milligrams $CaCO_3$ per liter) and slightly saline (1000 to 3000 milligrams per liter total dissolved solids).

In the Bodo Canyon south ephemeral drainage channel, the first sampling location (Site 4) is approximately 100 yards upgradient from the confluence of the Bodo Canyon drainage and the Animas River. The other two locations, Sites 7 and 7A, are near the head of Bodo Canyon. Site 7A was used as a sampling site only when insufficient flow occurred at Site 7.

Each site was scheduled to be sampled on a monthly basis for a period of 1 year; however, insufficient flow in the drainage channel allowed for only four samplings of Site 4 and five samplings of Sites 7 and 7A. Parameters analyzed that exceeded either state or Federal drinking water standards included sulfate, total dissolved solids, total iron, total manganese, total lead, total mercury, and gross alpha, as also shown in Table 6.3.

Surface water from the south drainage is classified as magnesium sulfate to mixed cation-sulfate type and slightly to moderately saline (1000 to 10,000 milligrams per liter total dissolved solids). The water ranges from moderately hard to very hard (61 milligrams per liter of $CaCO_3$ to greater than 180 milligrams per liter).

All the analytical results for all samples collected from the north and Bodo Canyon drainage are reported in the Draft Environmental Impact Statement (DEIS) (DOE, 1984).

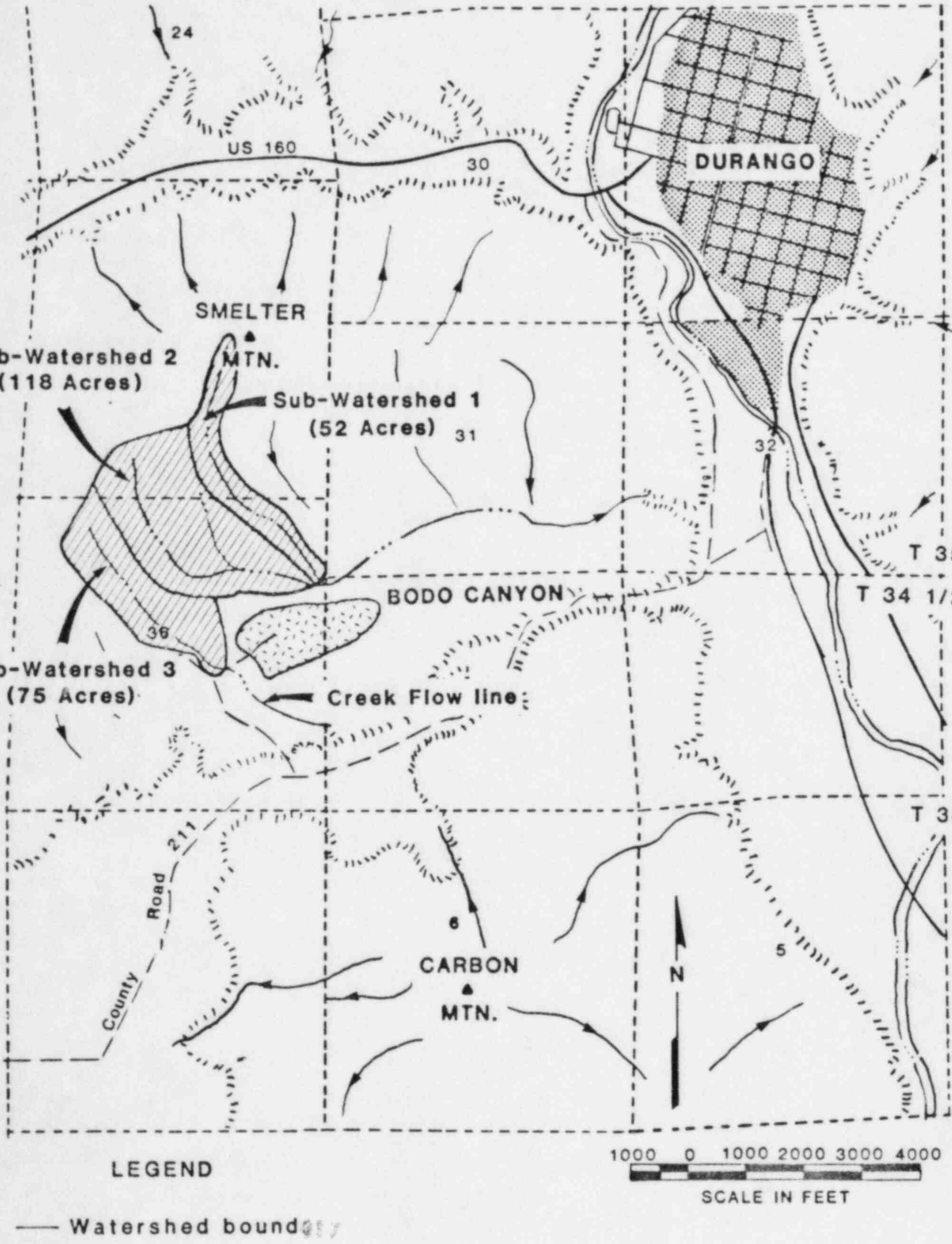


FIGURE 6.1
BODO CANYON WATERSHEDS

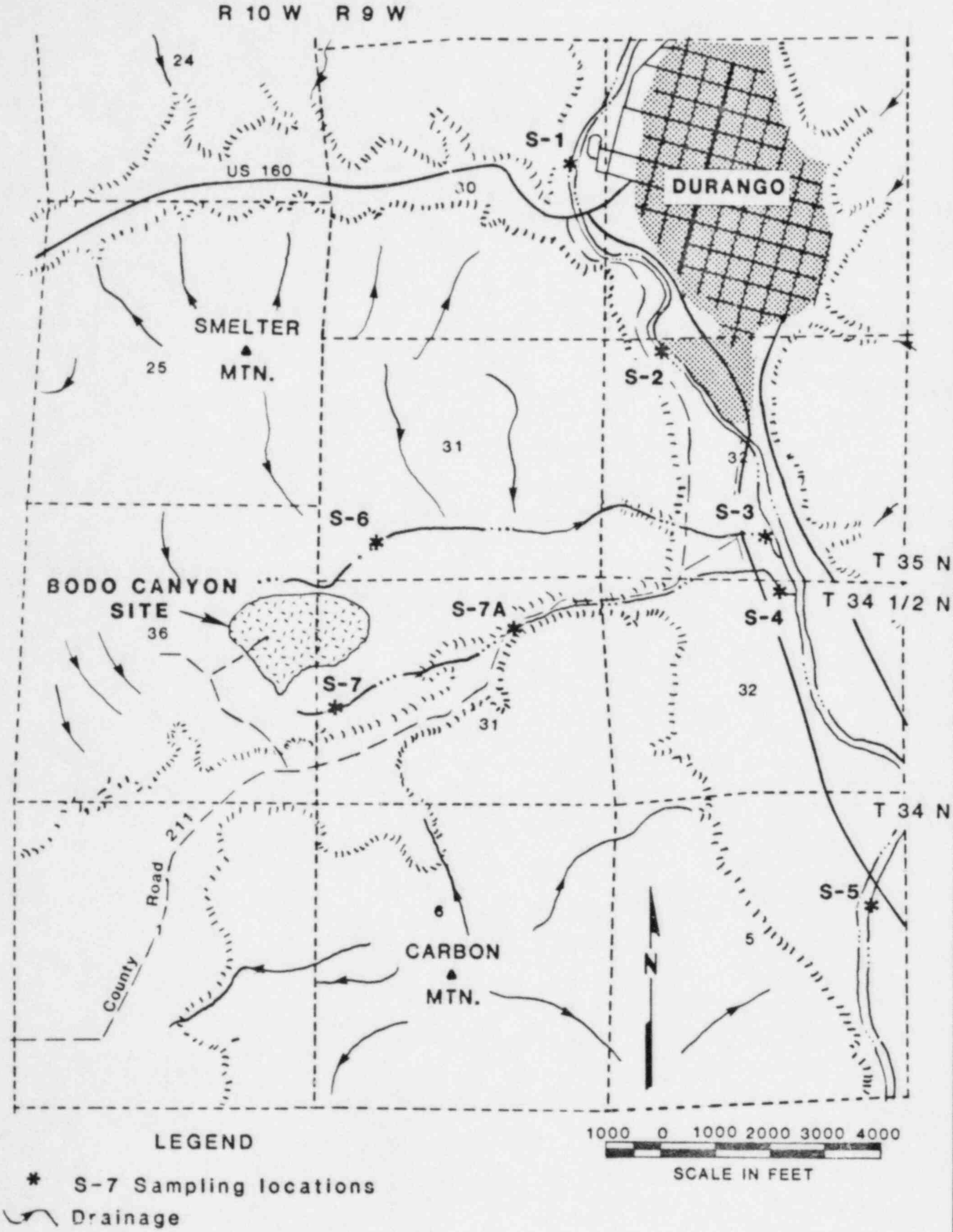


FIGURE 6.2
SURFACE-WATER SAMPLING LOCATIONS

Table 6.1 Precipitation distribution at 5-minute intervals, Bodo Canyon

Minutes	Precipitation (inches) Incremental	Precipitation (inches) Accumulative	Minutes	Precipitation (inches) Incremental	Precipitation (inches) Accumulative	Minutes	Precipitation (inches) Incremental	Precipitation (inches) Accumulative
5	0.01	0.01	125	0.08	0.72	245	0.05	10.19
10	0.02	0.03	130	0.08	0.80	250	0.05	10.24
15	0.02	0.05	135	0.10	0.90	255	0.05	10.29
20	0.02	0.07	140	0.10	1.00	260	0.04	10.33
25	0.02	0.09	145	0.10	1.10	265	0.04	10.37
30	0.02	0.11	150	0.12	1.22	270	0.03	10.40
35	0.02	0.13	155	0.13	1.35	275	0.03	10.43
40	0.02	0.15	160	0.15	1.50	280	0.03	10.46
45	0.02	0.17	165	0.15	1.65	285	0.03	10.49
50	0.02	0.19	170	0.30	1.95	290	0.03	10.52
55	0.02	0.21	175	0.60	2.55	295	0.03	10.55
60	0.02	0.23	180	1.90	4.45	300	0.02	10.57
65	0.02	0.25	185	2.70	7.15	305	0.02	10.59
70	0.03	0.28	190	1.50	8.65	310	0.02	10.61
75	0.03	0.31	195	0.40	9.05	315	0.02	10.63
80	0.03	0.34	200	0.20	9.25	320	0.02	10.65
85	0.03	0.37	205	0.15	9.40	325	0.02	10.67
90	0.03	0.40	210	0.15	9.55	330	0.02	10.69
95	0.03	0.43	215	0.13	9.68	335	0.02	10.71
100	0.03	0.46	220	0.10	9.78	340	0.02	10.73
105	0.04	0.50	225	0.10	9.88	345	0.02	10.75
110	0.04	0.54	230	0.10	9.98	350	0.02	10.77
115	0.05	0.59	235	0.08	10.06	355	0.02	10.79
120	0.05	0.64	240	0.08	10.14	360	0.01	10.80

Table 6.2 Drainage areas, lag times, curve numbers, and PMF peaks for Bodo Canyon watersheds

Sub-watershed	Drainage area (acres)	Lag time (hours)	Curve number	PMF peak (cfs)[a]
1	52	0.12	93	1138
2	118	0.09	93	2707
3	75	0.10	93	1740

[a]Cubic feet per second

Ref. Dames and Moore, 1983b.

Table 6.3 List of parameters which exceeded state or Federal drinking water standards in the Bodo Canyon area

Parameter	Federal standard	State standard	Date sampled	Location number[a] S-3		S-6
1. NORTH DRAINAGE						
Total iron	0.3	0.3	02/22/83	0.33		14.0
Total lead	0.05	0.05	02/22/83	<0.01		0.07
Total manganese	0.05	0.05	02/22/83	0.02		0.17
Total dissolved solids	500	--	03/23/82	2075		2159
			02/22/83	1446		1074
Total sulfate	250	--	03/24/82	1267		1376
			02/22/83	877		613
Sulfate	---	250	03/23/82	1267		1340
			02/22/83	877		610
Radium 226-228 combined (total)	5.0	--	03/23/82	8.1±2.4		4.1±2.2
			02/22/83	3.9±2.2		7.3±2.1
Gross alpha (total)	15.0	--	02/22/83	3.0±4.8		19.7±10.4
Gross alpha	15.0	--	03/24/82	18.2±18.8		9.2±13.0
2. SOUTH DRAINAGE						
Total iron	0.3	0.3	03/23/82	0.38	0.79	NS
			05/03/82	0.52	NS	NS
			11/01/82	NS	NS	0.55
			02/22/83	NS	NS	15
Total lead	0.05	0.05	02/22/83	NS	NS	0.07
Total manganese	0.05	0.05	03/23/82	0.03	0.09	NS
			02/22/83	NS	NS	0.20

Table 6.3 List of parameters which exceeded state or Federal drinking water standards in the Bodo Canyon area (Concluded)

Parameter	Federal standard	State standard	Date sampled	Location number[a] S-4	S-7	S-7A
Total dissolved solids	500	--	03/23/82	1801	2400	NS
			05/03/82	2312	NS	NS
			06/08/82	2454	NS	2486
			06/22/82	2562	NS	2630
			11/01/82	NS	NS	3066
			02/22/83	NS	NS	994
Total sulfate	250	--	03/23/82	1053	1490	NS
			05/03/82	1385	NS	NS
			06/08/82	1495	NS	1496
			06/22/82	1613	NS	1547
			11/01/82	NS	NS	1788
			02/22/83	NS	NS	610
Sulfate	---	250	03/23/82	1053	1473	NS
			05/03/82	1378	NS	NS
			06/08/82	1485	NS	1481
			06/22/82	0577	NS	1538
			11/01/82	NS	NS	1786
			02/22/83	NS	NS	610
Radium 226-228 combined (total)	5.0	--	02/22/83	NS	NS	6.6±2.2
Gross alpha (total)	15.0	--	06/08/82	27.2±23.2	NS	25.4±30.5
			06/22/82	70.4±48.6	NS	50.8±42.3
			02/22/83	NS	NS	36.7±18.9

[a]For sampling locations see Figure 6.2.

NOTES: All values reported on a dissolved basis in milligrams per liter, unless otherwise noted.

NS - Not sampled.

--- No value.

Reported values for combined radium and gross alpha in picocuries per liter.

7.0 GEOTECHNICAL DATA

7.1 PURPOSE

An evaluation of the geology and site subsoils is required to:

1. Evaluate the end of construction, long-term, and seismic stability.

2. Estimate possible settlement or consolidation of the soils.

3. Evaluate geomorphic longevity.

4. Provide the design basis for road access to the site.

5. Evaluate suitability of radon borrow materials.

6. Evaluate tailings fill characteristics.

7.2 SEISMICITY AND SEISMIC HAZARDS

A seismic hazard study of the Durango, Colorado, area was undertaken as a part of an assessment of the long-term stability of an existing uranium mill tailings pile and two alternate disposal site areas. Both deterministic and probabilistic approaches were used.

Several accelerations of 0.01 to 0.02g have probably occurred in the site area since 1960, based on an assessment of recent seismic activity. The maximum potential horizontal acceleration in rock expected at the site area during a Maximum Credible Earthquake (MCE) related to a specific known seismogenic feature is found to be 0.09g, resulting from a magnitude 7.5 earthquake in the Dulce, New Mexico, area. Accelerations greater than 0.5g could result from earthquakes of magnitude 6.5 occurring on previously unrecognized faults within a few miles of the site; however, the probability of such events occurring during the design life of the planned facility is calculated to be very small.

The probability of occurrence of various levels of acceleration for various time periods was calculated using the computer code ACC.LINE.AREA. Summarized values are as follows:

- o Ten-year time interval - less than 10 percent probability of occurrence of an acceleration exceeding 0.05g.
- o Two hundred-year time interval - less than 10 percent probability of occurrence of an acceleration exceeding 0.09g.
- o One thousand-year time interval - less than 10 percent probability of occurrence of an acceleration exceeding 0.12g.

Field studies including surface reconnaissance, low sun aerial reconnaissance, and on-site and near-site trenching show no indications of active faulting in the vicinity of Bodo Canyon.

Appendix B, Seismic Risk Evaluation, presents a detailed discussion of the seismic hazard associated with the Bodo Canyon site.

7.3 MINERAL RESOURCES

The Menefee Formation, which underlies the Cliff House Sandstone at a depth of about 140 feet below the Bodo Canyon disposal site, is a primary source of coal in the San Juan Basin (ARPC, 1976). The disposal site could be underlain by as much as 400,000 tons of potentially recoverable coal based on the total reserve calculations for T35N, R10W (Zapp, 1949). Coal beds ranging in thickness from 0.25 to 6.5 feet occur in the upper 75 feet of the Menefee Formation in Bodo Canyon (see Lithologic Field Logs, Appendix C) and at least 10 abandoned coal mines and prospects in the Menefee Formation are located within a 1-mile radius of the disposal site. Drilling at the Bodo Canyon disposal site in December, 1984, verified the presence of coal seams beginning at about 145 feet below the surface. One boring at the east end of the disposal site, extending a total depth of 200 feet, intercepted five coal seams totalling about 15 feet in the internal between 145 and 200 feet. A boring at the west end of the disposal site intercepted nine coal seams totalling about 26 feet in the interval from 145 feet to the total hole depth of 255 feet (see Appendix C). The thickest of the coal beds encountered, 6.5 feet thick, occurs about 50 feet below the top of the formation or about 170 feet below the ground surface at the disposal site. Based upon the limited deep drilling, the continuity of the coal seam underlying the disposal site cannot be fully defined.

La Plata County has a large number of producing oil and gas wells. However, most of the wells have been drilled some distance east of the disposal site, principally into the Dakota Sandstone. No wells are known to have been drilled in the immediate vicinity of Bodo Canyon (CGS, 1981). However, two unsuccessful test holes were drilled in the Ridges Basin. Both were plugged and abandoned; however, one was left open to a depth of 1950 feet for use as a water well (USBR, 1980).

The surface alluvium contains a perched water table that is not considered to be a significant water resource for the area.

7.4 GEOTECHNICAL CONSIDERATIONS

7.4.1 In-situ subsurface soils

Subsurface soil conditions at the proposed Bodo Canyon disposal site were investigated in two efforts both contracted by the DOE.

One investigation was undertaken by Dames and Moore beginning with field explorations in late October and early November of 1982. Twelve borings, designated as B-1 through AH-8, were drilled at the Bodo Canyon disposal site (which has previously been referred to as "Area E"). These borings were advanced to depths ranging from 35.0 to 122.8 feet. Boring AH-8 was drilled and sampled to a depth of 64 feet for geotechnical purposes then

completed as a ground-water monitoring well. Test pits TP-10 and TP-11 were excavated to obtain bulk samples of the existing near surface soils.

Efforts undertaken by the TAC beginning with field investigations in July of 1984, included 10 test pits (designated DUR 03-500 through DUR 03-509) used to obtain bulk samples for lab testing, and four borings (designated DUR 03-601 through DUR 03-604). The test pits went to depths ranging from 3 to 12 feet, while the borings went to depths ranging from 42.3 to 255 feet. The shallower boreholes (DUR 03-601 and DUR 03-604) were logged, the soils were visually classified, and selected disturbed and undisturbed samples were taken for later testing. The deep boreholes (DUR 03-602 and DUR 03-603) were augered down to bedrock (with no soils logging) and cored, logged, and pressure tested to depths of 200 and 255 feet respectively. All four holes were completed and converted to monitoring wells. (Refer to Figure 7.1 for the locations of both the D&M and TAC boreholes and test pits. Copies of the logs of the above mentioned boreholes and test pits can be found in Appendix C, Lithologic Field Logs.)

Eight different soil series are located in the vicinity of the disposal site with three types, Falfa, Zyme, and Sili, representing the majority of the soils in the area. The physical properties of the three soils series that were sampled are listed in Table 7.1 and results of the chemical analyses performed are summarized in Table 7.2.

The clay and silt overburden soils vary in depth from as much as 65 feet (in the center of the site) to as little as one foot (along the north edge of the site) below the existing grade. As mentioned in the geology section, the surface soils are underlain by sandy shale bedrock. The upper 5 to 35 feet of the shale are fractured and unweathered to moderately weathered. Below the weathered layer, the sandy shale is essentially monolithic to a depth of at least 145 feet (Boring DUR 03-602) with an occasional layer of dense sandstone and infrequent fractures. However, the normal structure of shale is such that there are extensive areas where closely spaced, nearly horizontal partings occur.

Typical sections (A-A', B-B', and C-C'), locations of which are indicated on Figure 7.1, showing subsurface profiles are presented in Figures 7.2 through 7.4.

Engineering characteristics of in-situ soils at Bodo Canyon

As mentioned above and indicated on the profiles, the soils at the Bodo Canyon site consist of very low to medium plasticity clayey silts and sandy to silty clays (CL, CH, ML, and ML-CL) that extend to a maximum depth of about 65 feet. This material is generally of medium density with the dry unit weights ranging from about 98 pcf to 114 pcf. The soil moisture contents ranged from about 8.6 percent to 24.4 percent. These values indicate a range from dry to near saturation. Since field explorations were performed during the late fall season as well as in mid-summer, the

moisture contents probably indicate a range between the extremes of wetness caused by weather changes with the seasons. The upper zone of the surficial soils most likely experiences significant drying during the summer months and reduced moisture contents.

Classification and specific gravity tests were performed by Dames and Moore and are shown in Tables 7.3, 7.5 and 7.9. The same tests (including moisture contents) were performed on bulk samples by the TAC and the results are presented in Tables 7.4, 7.6, 7.7, 7.8, and 7.10.

Strength, consolidation, and permeability properties of in-situ site soils

Soil permeability values based on two permeability tests were 9.7×10^{-9} centimeters per second and 3.0×10^{-7} centimeters per second which is relatively low. The largest permeability value was recorded on a sandy silty clay sample taken at a depth of 46.5 feet in Boring B-1. The soil permeability values are given in Table 7.11.

Consolidation tests were performed by Dames and Moore (D&M) on two relatively undisturbed samples from Borehole B-2 at depths of 11.5 and 36.5 feet below grade. These samples had dry densities of 101 pcf and 102 pcf and soil moisture contents of 22.9 and

24 percent respectively. The soils tested were low and medium plasticity silty clay and clay (CL, CH). The consolidation test results, presented in Table 7.12, indicate the site soils are slightly overconsolidated at depth while, near the surface they are highly overconsolidated. The virgin compression index values were 0.257 to 0.252, as determined using percent consolidation versus log of pressure graphs. The overconsolidation has most likely been caused by high capillary tension induced by the desiccation and wetting process that the near surface soils experience on a periodic basis.

Soil strengths were determined by D&M using field shear tests as well as triaxial shear tests performed in the laboratory on selected relatively undisturbed samples. Twenty-two field shear tests were run at various depths in the 6 D&M borings while 10 triaxial shear tests were performed on relatively undisturbed samples of soils of similar unit weight, moisture content, and classification from the same borings. The triaxial shear test results are shown in Tables 7.13 and 7.14. The field shear test results are presented in Table 7.15.

Dispersivity of on-site soils

On-site soils seem to vary in their susceptibility to water erosion (or dispersivity). Tests performed by D&M indicated nondispersive soils while those performed by the TAC indicated highly dispersive soils. For a more detailed discussion of dispersivity

and test results see Section 7.6.2, Radon Barrier Materials, under the subsection entitled Lime Stabilization of On-site Borrow Soils.

7.4.2 Radon barrier materials

Off-site borrow soils

In their 1982 investigation of alternate disposal sites, D&M dug a number of test pits at the Bodo Canyon site (see Figure 2.1). In addition to being a possible alternate disposal site, they also considered this area as a possible borrow site for radon barrier (cover) materials. In order to determine the soil types and properties of these soils, bulk samples were obtained at depths of 4.0 to 4.5 feet and 11.5 to 12 feet from test pit number 4 (TP-4) and tested in the laboratory. The soils from TP-4 were found to be low plasticity silty clays (Table 7.16) with moisture contents of 15.9 and 18.0 percent (Table 7.17).

In order to determine how these soils would behave as construction materials, modified Proctor compaction tests were run and the moisture-density relationships were determined (Table 7.18). Following this, a series of tests were run on remolded samples to determine their engineering properties at 90 percent of maximum density as determined by the modified Proctor method.

The soils from Area E were found to have permeabilities ranging from 1.0 x 10^{-10} to 1.0 x 10^{-9} centimeters per second (Table 7.19). Consolidation tests indicated that these soils have a virgin compression index of 0.113 and show a preconsolidation pressure of 43,000 psf (Table 7.20). However, the relatively high compactive effort needed to attain 90 percent of modified Proctor maximum density results in a very high preconsolidation pressure, and thus it should be noted that the post construction settlements may best be calculated using the lower rebound compression index since post-construction effective stresses will not exceed the preconsolidation pressure (Table 7.20). No strength testing was done on samples from Area E.

On-site borrow materials

Soils that can possibly be used for radon barrier material exist on the proposed Bodo Canyon disposal site. As mentioned earlier, low to medium plasticity silts and sandy to silty clay soils underlie the site to depths of as much as 65 feet below the present ground surface.

In order to investigate the feasibility of using these on-site soils as cover material, both D&M and the TAC utilized bulk samples from test pits in laboratory testing programs. Test pit locations are shown on Figure 7.1. Individual test pit logs are contained in Appendix C, Lithologic Field Logs.

D&M tested samples from test pits 10 and 11 (individually and combined) in order to determine their properties. It was found that, although the samples from TP-10 and TP-11 were classified as low plasticity clays, the combined sample was a high plasticity clay.

The TAC tested remolded bulk samples from three of six TAC test pits. The soils tested were low plasticity sandy and silty clays from DUR 03-500, DUR 03-503, and DUR 03-508 (see Table 7.4).

Compaction tests were performed by D&M on a sample from TP-10 as well as a combined sample and the results are presented in Table 7.21. The results of the compaction tests performed by the TAC are likewise presented in Table 7.22.

In order to determine the engineering behavior of the on-site soils, both D&M and the TAC performed a series of similar tests on recompacted test pit samples. D&M tested both individual and combined samples from TP-10 and TP-11 at 90 percent of modified Proctor maximum density while the TAC tested individual samples from test pits DUR 03-500, DUR 03-503, and DUR 03-508 at 95 percent of standard Proctor maximum density.

The TAC remolded permeability tests indicated a wide range in saturated permeabilities with the highest being 7.7×10^{-6} centimeters per second for a low plasticity borderline silt-clay soil (CL-ML) and the lowest being 1.9×10^{-9} centimeters per second for a low plasticity clay (Table 7.23).

However, since research has shown that as the saturation level of a soil drops below 100 percent the permeability or hydraulic conductivity tends to decrease, it is therefore necessary to determine the unsaturated hydraulic conductivity of the site soils. Since unsaturated hydraulic conductivity tests are very difficult to perform and the results are not highly reproducible, it was decided that empirical methods should be used. Several methods were considered (SHB, 1984a) and it was determined that the Modified Millington - Quirk method (LBL, 1984) would be used to determine the unsaturated hydraulic conductivities. The Modified Millington - Quirk method uses the results of capillary moisture tests and the saturated permeability of the soil to calculate the unsaturated hydraulic conductivity at various water contents. Thus, for this and other uses, the TAC performed capillary moisture tests on three remolded samples. The results of these tests are presented in Table 7.24.

The calculated unsaturated hydraulic conductivities varied from a low of 4.8×10^{-15} cm/sec for a sample from DUR03-500 at 73 percent saturation to a high, equal to the saturated permeability, of 7.8×10^{-3} cm/sec for a sample from DUR03-503 at 100 percent saturation. The calculated unsaturated hydraulic conductivity values are presented in Table 7.25.

Consolidation tests performed by D&M showed the virgin compression index to vary between 0.153 and 0.206 with preconsolidation pressures being in excess of 20,000 psf. As has been been

previously noted, these preconsolidation pressures created by compaction to 90 percent of modified Proctor maximum density will cause post construction settlements to be in a range best calculated using the lower rebound compression indexes (Table 7.26).

Consolidation tests run by the TAC on remolded samples from test pits DUR 03-500 and DUR 03-503 indicate that the virgin compression index for these low plasticity clays is in the range of 0.107 to 0.233 (Table 7.27) which is in good agreement with the values obtained by D&M. However, due to the lower compactive effort required to attain 95 percent of standard Proctor maximum density, the preconsolidation pressures were as low as 2200 psf. Thus, if the cover embankment is compacted to the same density specifications as were the TAC test samples, it will not be obvious whether to use the lower rebound compression index until the actual cover thicknesses are determined.

Both D&M and the TAC performed unconsolidated - undrained ("Quick" or UU) triaxial shear tests as well as consolidated - undrained ("Rapid" or CU) triaxial shear tests (with pore pressures monitored) on specimens remolded from test pit bulk samples. The results of the D&M and TAC UU tests are found in Tables 7.28 and 7.29, respectively, while results of the CU tests are presented in Tables 7.30 and 7.31, respectively.

In reviewing the results of these triaxial shear tests, two major differences between the D&M and TAC samples should be noted:

1. The D&M samples were classified as CH soils while the TAC samples classified as CL.

2. The D&M samples were compacted to 90 percent of modified Proctor maximum density whereas the TAC samples were compacted to 95 percent of standard Proctor maximum density.

Due to the above stated differences, no direct comparison of the test results is recommended.

The consolidated undrained tests on the TAC samples showed friction angles of 22.5 and 31.6 degrees with cohesion intercepts of 300 and 100 psf respectively. These values are considered representative of the values expected for silty clay soils. The D&M sample exhibited a friction angle of 18 degrees with a cohesion intercept of 2225 psf in the CU test. These values are within the range of reasonable expected values for a CH soil.

The UU test results indicate that the CL soils tested by TAC have a lower cohesion value than do the CH soils tested by D&M. This result is as would be expected given the differences in sample preparation and soil type.

Lime stabilization of on-site borrow soils

Soils with a plasticity index greater than 15 have been found to have a potential for swelling when the water content is caused

to increase from an existing water content that is below the plastic limit of the soil (G.F. Sowers, 1979).

The in-situ soils have plasticity indexes that vary between 5 and 33 while having moisture contents at or somewhat below their plastic limits (Tables 7.8 and 7.4). This means that some of these foundation soils may have a high potential for swell, especially if they dry out somewhat and are later saturated. If these same soils are used as cover material and compacted at a moisture content near optimum there will be at least a moderate potential for swell, especially if the modified Proctor optimum moisture is specified.

In order to verify the above stated empirical relation, swell tests were performed by the TAC on a recompacted bulk sample from test pit DUR 03-500. These tests indicated that the unconfined soil may expand up to 1.5 percent or, if confined, will generate an expansion pressure of about 1700 psf (Appendix D, Laboratory Test Data, Foundation Soils).

The swell potential of the on-site soils indicates the need to treat these soils in order to reduce this potential to a reasonable level. Past experience has shown that small amounts of lime blended with a soil prior to recompaction can reduce its swell potential.

Therefore, in order to test the effectiveness of lime stabilization of the soils at the Bodo Canyon disposal site, the TAC ran a series of tests on soils that were mixed with 4 percent lime and recompacted to 95 percent of standard Proctor maximum density. Swell tests on these samples mixed with 4 percent lime indicated that the swell induced by increased moisture content is essentially zero and that swell pressures will thus be very nearly zero (Appendix D, Laboratory Test Data, Foundation Soils).

Another important aspect of design is the ability of the cover and foundation soils to resist erosion. Both D&M and the TAC tested various samples to determine whether the on-site and borrow soils are dispersive or non-dispersive and thus determine their ability to resist erosion by flowing water.

D&M performed two pinhole dispersion tests; one on an undisturbed sample recovered from a depth of 16.5 feet in borehole B-2 and a second on a recompacted sample from test pit TP-4 in area D. Both of these soils were found to be nondispersive (Table 7.32). The TAC performed three different tests on remolded samples from test pit DUR 03-503. All three tests (Double Hydrometer, Pinhole test, and Crumb test) indicated that this soil is highly dispersive (Table 7.33) and thus easily eroded by water.

The addition of lime to a soil will tend to reduce its dispersion or erosion potential. To determine the effect of lime treatment on the on-site soils, the TAC performed dispersion tests on recompacted samples from the same test pit.

The test results indicate that the addition of 4 percent lime to the soil makes it nondispersive (Table 7.34) and thus very resistant to erosion by flowing water. This reduction in dispersivity is further evidenced by the reduction in the plasticity index of all the samples (Table 7.35).

Compaction tests on lime treated samples showed a decrease in maximum density and an increase in optimum moisture in every case (Table 7.35). A triaxial back pressure saturated permeability test on a lime treated sample from test pit DUR 03-508 showed a permeability of 1.7×10^{-6} centimeters per second indicating an increase in permeability in the lime treated soil sample of almost 2 orders of magnitude over the untreated sample (Table 3.35). Capillary moisture tests were also performed on the lime treated soils and the results of these tests are presented in Table 7.36.

Long term moisture content and radon diffusion coefficients of on-site radon barrier borrow materials

Since a maximum average flux of 20 pCi/m^2s for radon emanating from the stabilized tailings has been set forth as a guideline by EPA, it is necessary to determine the thickness of cover materials required to meet this standard.

Past experience has shown that the most important factors affecting radon flux and thus cover thickness, excluding the factors

controlled by the nature of the tailings themselves, are the cover moisture content and the radon diffusion coefficient of the cover material. It has also been found that these factors are interdependent, thus underscoring the important effect the long-term moisture content has on cover thickness design.

Capillary moisture test information, calculations based on various theoretical approaches to capillary moisture content, and previous experience were combined to estimate the probable range in long-term moisture contents of the on-site cover soils. The estimated long range moisture contents of various soil samples are presented in Table 7.37.

Once the long-term moisture content of the cover is determined, it is necessary to test the soil over a range of moisture contents around the long-term moisture content in order to determine the expected range of radon diffusion coefficient values. The results of these tests are summarized in Table 7.38.

As indicated in the above mentioned tables, the long range moisture content varied between 14 and 23 percent while the radon diffusion coefficient varied between 1.8×10^{-4} and 2.2×10^{-2} cm^2/s when tested at moisture contents ranging from 6.5 to 21.7 percent.

7.4.3 Erosion protection materials

Off-site borrow areas

Two potential quarries for rock resources were located as shown in Figure 2.1 (Dames and Moore, 1983b). Laboratory tests, including Los Angeles abrasion and sodium sulfate soundness, were performed and the results are presented in Tables 7.39 and 7.40.

The same tests were performed by the TAC on samples of slag from the Durango processing site. The results of these tests are presented in Table 7.41.

On-site erosion protection materials

There is no significant source of suitable rock located within the site boundaries.

7.5 DATA EVALUATION

The site appears to be seismically stable and the data provided are sufficient to design the road improvements, define the appropriate site preparation program in order to minimize settlement problems, and design the cover and rock erosion protection as well as determine the approximate volumes and properties of the materials available for this use.

A visual examination to determine the presence of coal seam outcrops and abandoned coal mines in the Bodo Canyon area should be conducted by the TAC to determine the accessibility/exposure of the near surface resource (if any) underlying the disposal area. The information provided by the examination would be used to evaluate or design a program to determine the potential for subsidence under the disposal area caused by mining or burning of the coal resource.

7.6 DATA NEEDS

Additional laboratory test data on the Bodo Canyon in-situ foundation soils needs to be summarized in order to better understand the behavior of the pile during and following construction. The field seismicity studies need to be summarized and presented in Appendix B.

Tailings materials need to be sampled and tested in order to confirm values selected for use in design analysis.

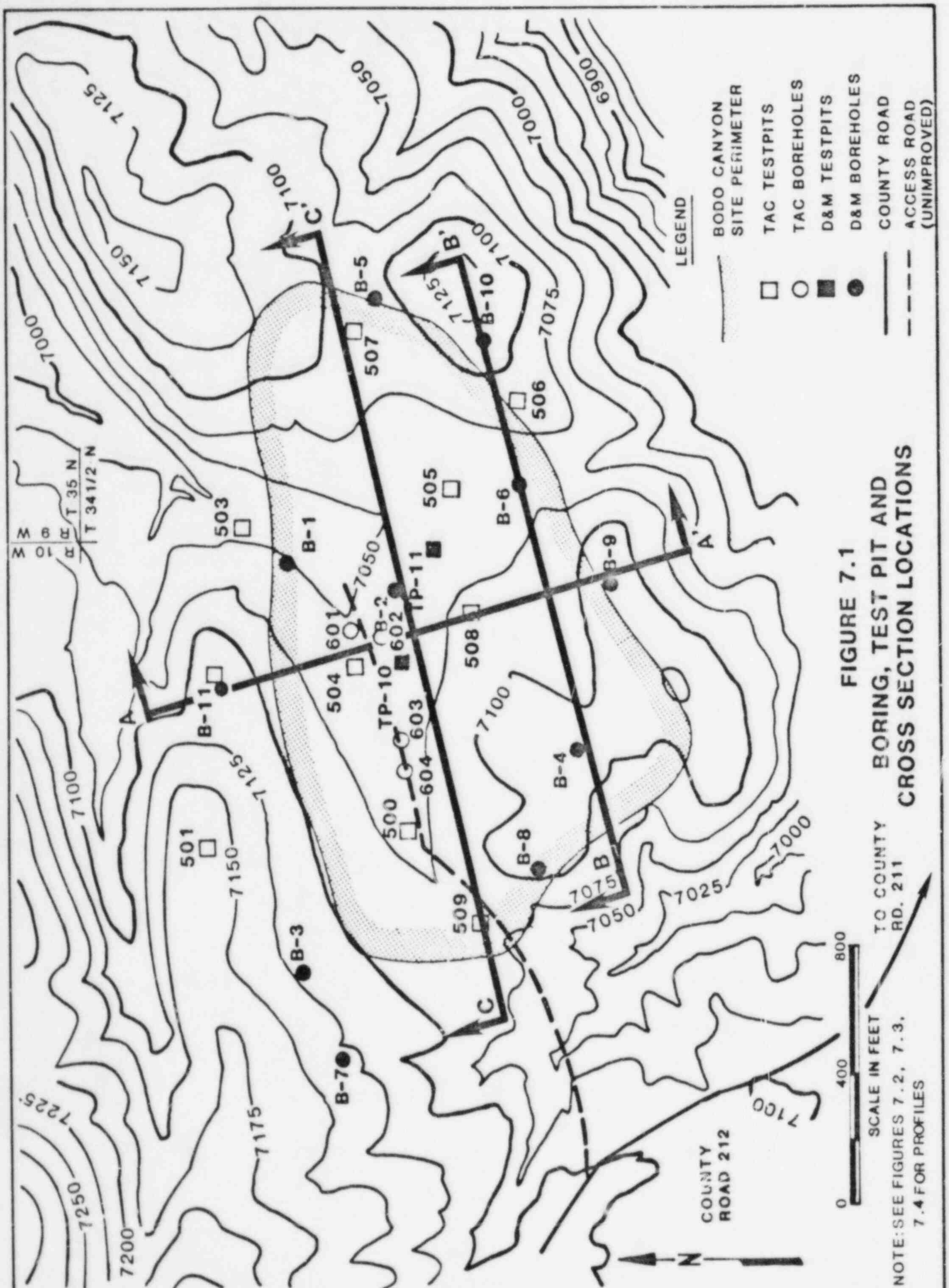


FIGURE 7.1
BORING, TEST PIT AND CROSS SECTION LOCATIONS

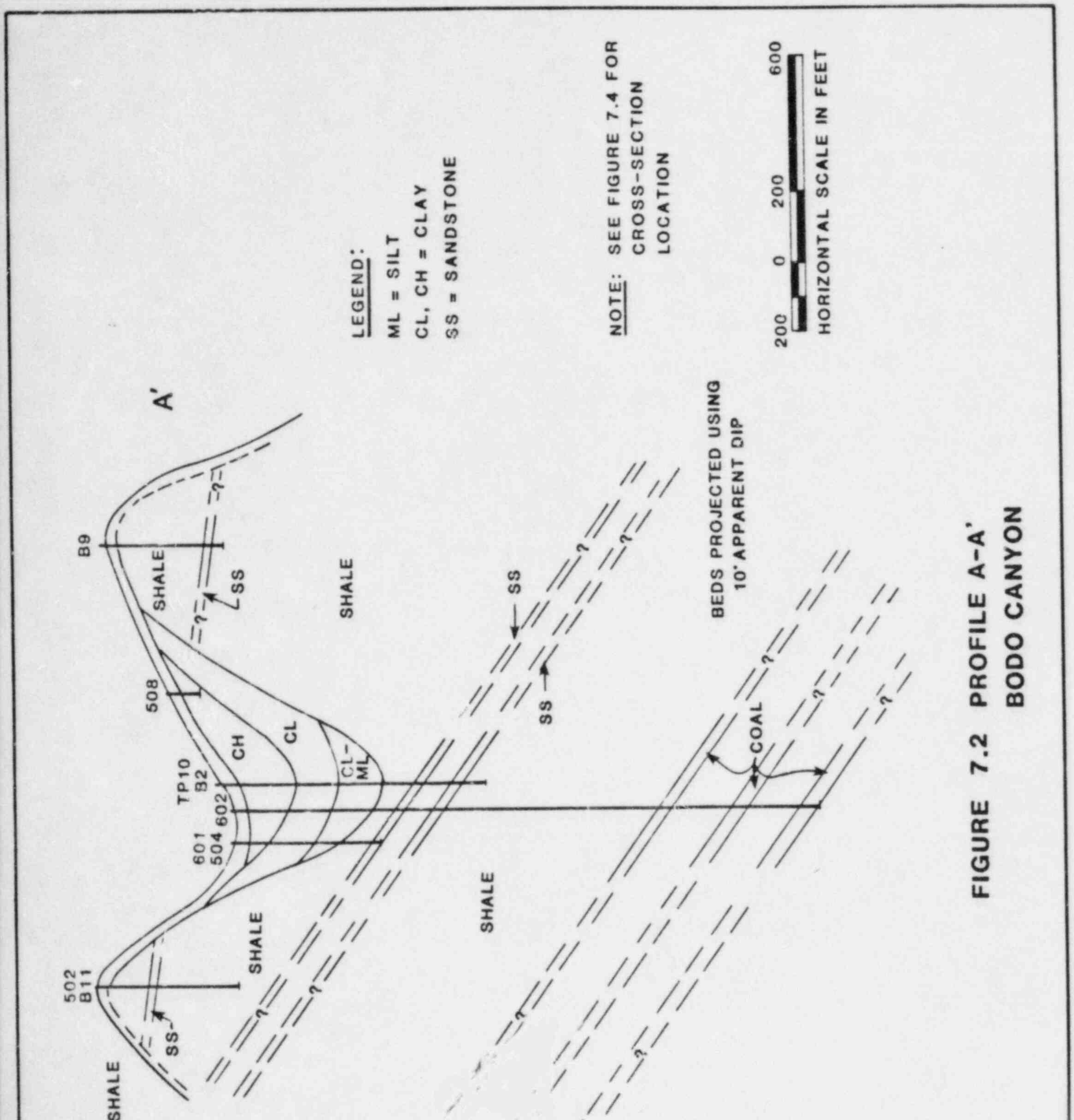
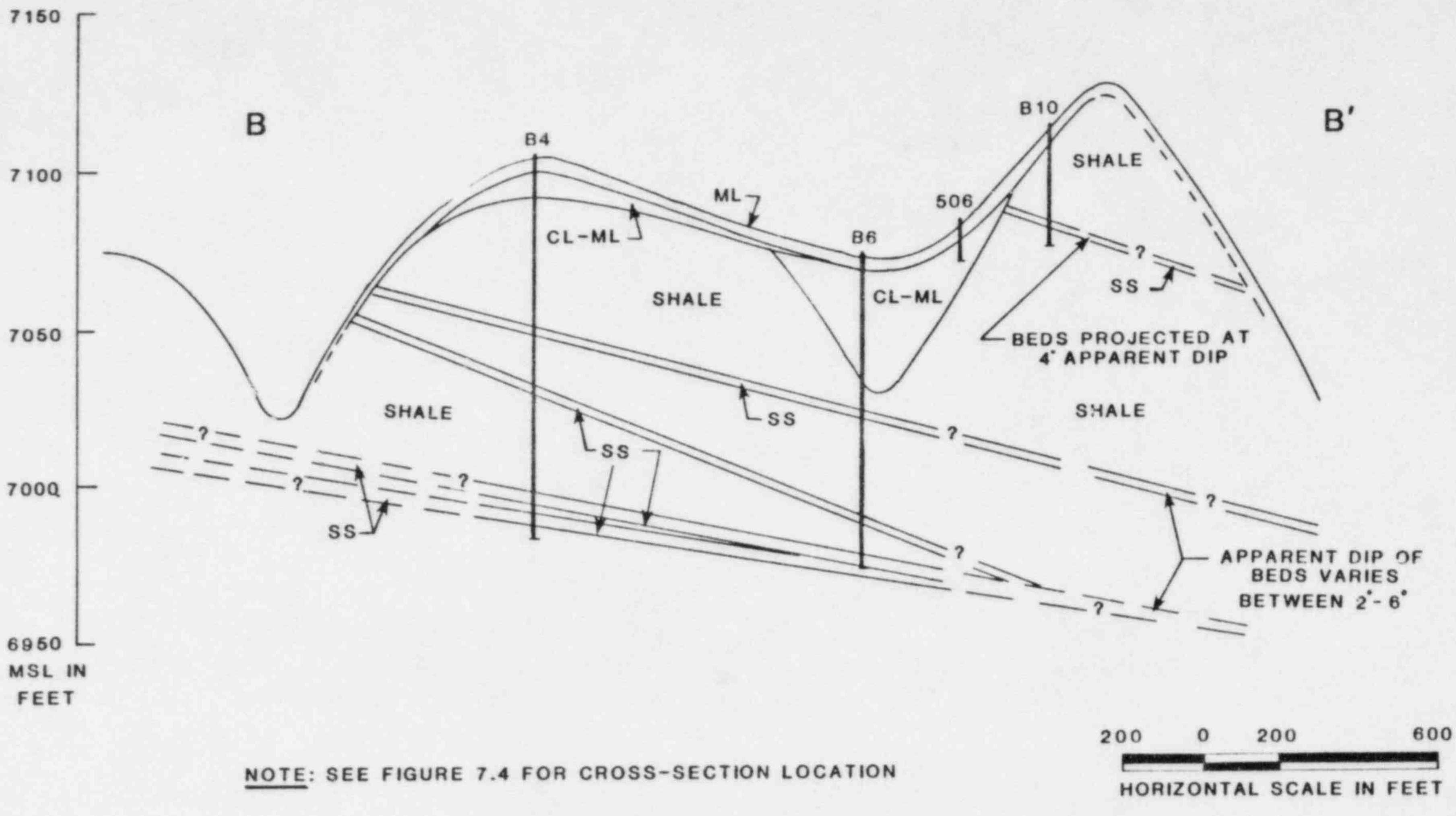


FIGURE 7.2 PROFILE A-A'
BODO CANYON



NOTE: SEE FIGURE 7.4 FOR CROSS-SECTION LOCATION

LEGEND:
ML = SILT
CL = CLAY
SS = SANDSTONE

**FIGURE 7.3 PROFILE B-B'
BODO CANYON**

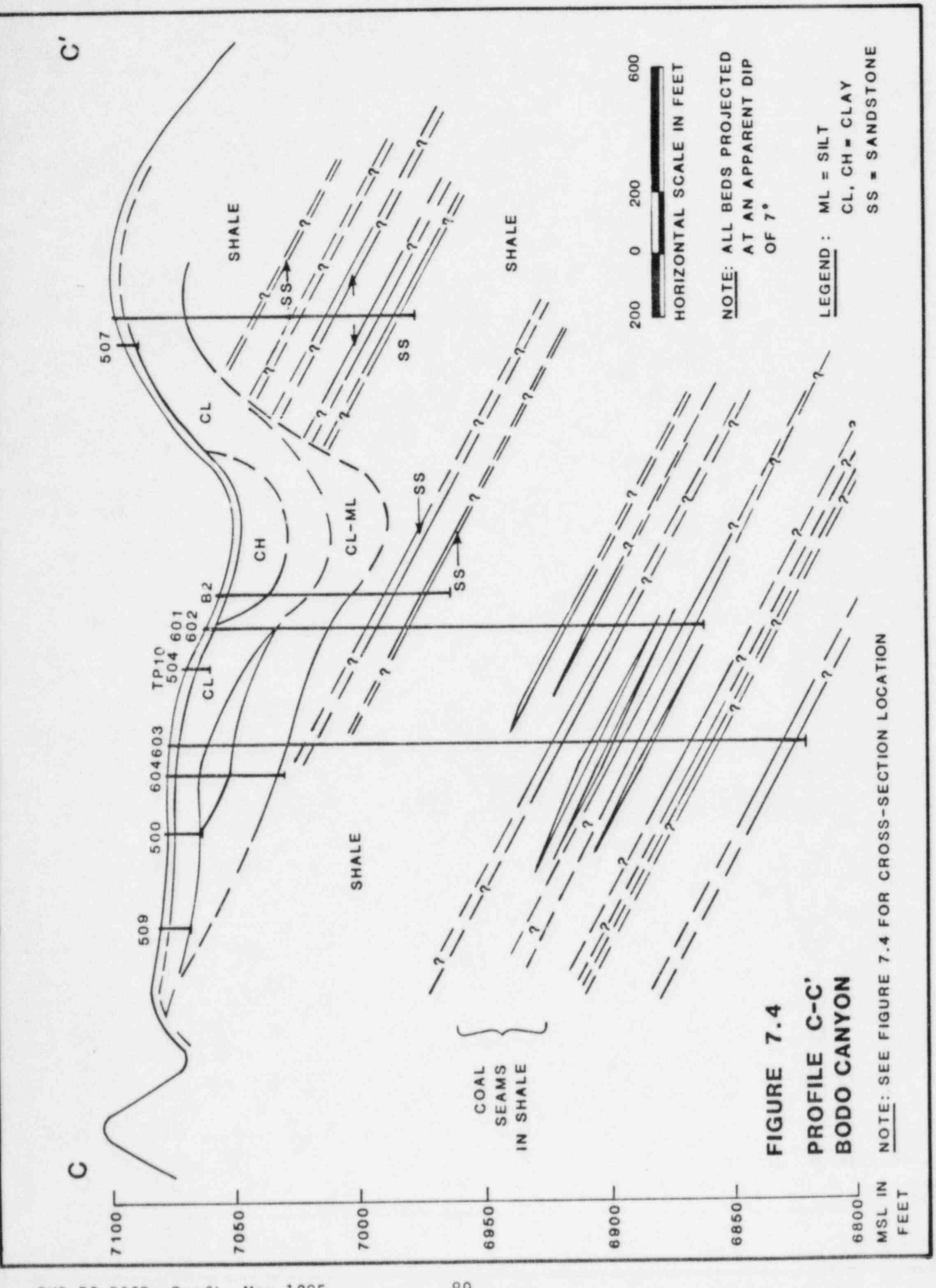


FIGURE 7.4
PROFILE C–C'
BODO CANYON

NOTE: SEE FIGURE 7.4 FOR CROSS-SECTION LOCATION

Table 7.1 Physical properties of typical soils in the Bodo Canyon area

Soil series and symbol	Depth	Textural class	Saturation percent	Drainage class	Dry consistency
Falfa (R8CD)	0- 4"	Loam	40.2	Well-drained	Soft
	4-12"	Clay loam	37.2		Hard
	12-44"	Clay	82.0		Very hard
	44-60"	Clay	72.9		Very hard
Zyme (E6CE)	0- 3"	Clay loam	27.2	Well-drained	Soft
	3-16"	Clay	73.7		Very hard
Sili (V7C)	0- 3"	Silty clay loam	60.3	Well-drained	Slightly hard
	3-17"	Clay loam	70.2		Very hard
	17-39"	Clay loam	71.9		Very hard
	39-60"	Clay loam	64.4		Very hard

Ref. Dames and Moore, 1983b.

Table 7.2 Chemical properties of soils sampled in the Bodo Canyon area

Sample site number	Soil series and symbol	Depth	pH	EC umhos per cm	Na meq/l	Ca meq/l	Mg meq/l	SAR	Se ppm	B ppm	$CaCO_3$ %	OM (%)	K ppm	NO^3 ppm	P ppm	CEC	XNa
1	Falfa (R8CD)	0-4"	6.7	0.43	0.7	1.4	0.6	0.7	ND (0.04)	0.02	ND (0.2)	1.62	10.0	13.3	44.6	19.5	0.1
		4-12"	6.5	0.31	0.8	1.9	0.6	0.72	ND (0.04)	0.12	ND (0.2)	1.03	2.6	ND (0.1)	39.6	19.1	0.1
		12-44"	7.0	0.32	1.1	1.2	0.7	1.10	ND (0.04)	0.32	ND (0.2)	1.35	1.6	2.7	28.4	37.4	0.3
		44-60"	7.9	0.49	2.4	1.8	0.8	2.10	ND (0.04)	0.94	ND (0.2)	0.74	1.5	0.5	30.0	27.5	0.5
2	Zyme (EbCE)	0-3"	6.1	0.20	0.5	0.9	0.4	0.62	ND (0.04)	0.02	ND (0.2)	1.35	2.2	4.0	29.6	14.2	ND (0.1)
		3-16"	6.0	0.19	0.4	0.8	0.5	0.49	ND (0.04)	0.02	ND (0.2)	1.93	2.2	2.7	25.8	22.2	0.3
3	Sili (V7C)	0-3"	6.7	0.63	0.7	2.3	2.5	0.45	ND (0.04)	0.02	ND (0.2)	2.31	15.7	35.5	40.0	24.1	0.1
		3-17"	7.5	2.94	4.8	20.0	20.4	1.10	ND (0.04)	0.36	6.1	1.79	3.5	4.0	32.4	24.9	0.9
		17-39"	7.3	9.09	52.1	180.0	80.2	7.40	ND (0.04)	0.70	8.8	1.38	2.2	6.7	33.8	23.9	5.5
		39-60"	7.3	10.50	62.7	18.7	97.4	8.30	ND (0.04)	0.02	8.0	1.25	2.6	5.3	27.4	19.6	5.8

Legend:

EC = Electrical conductivity.
SAR = Sodium adsorption ratio.
OM = Organic matter.
CEC = Cation exchange capacity, in milliequivalents per 100 grams.
XNa = Exchange sodium, in milliequivalents per 100 grams.
meq/l = Milliequivalents per liter.
ppm = Parts per million.
ND = Not detected at level given in parentheses.
Na, Ca, Mg = Soluble sodium, calcium, magnesium.
Se = Selenium.
B = Boron.
K = Potassium.
NO_3 = Nitrate.

P = Phosphate.

Ref. Dames and Moore, 1983b.

Table 7.3 Atterberg limits test results (D&M)

Boring or test pit number	Depth (feet)	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	Unified soil classification
B-1	4.0	27	19	8	CL
	26.5	44	19	25	CL
	31.5	33	17	16	CL
	36.5	28	16	12	CL
	41.5	30	18	12	CL
	46.5	25	21	4	CL-ML
	51.5	26	17	9	CL
	61.5	35	16	9	ML
B-2	11.5	62	26	36	CH
	16.5	63	24	39	CH
	31.5	28	20	8	CL
	36.5	31	15	16	CL
	41.5	23	22	1	ML
	51.0	26	19	7	CL-ML
B-3	6.5	23	18	5	CL-ML
B-4	6.0	28	21	7	CL-ML
B-5	6.5	34	17	17	CL
	21.5	30	19	11	CL
	26.0	28	17	11	CL
B-6	16.5	26	19	7	CL-ML
	21.5	35	17	18	CL
	31.0	25	19	6	CL-ML
B-7	4.0	23	17	6	CL-ML

Ref. Dames and Moore, 1983b.

Table 7.4 Atterberg limits test results (TAC)

Sample No.	Depth interval (feet)	Liquid limit (%)	Plastic limit (%)	Plasticity index (PI) (%)	Unified soil classification
DUR-03-500-001	4-8	36	17	19	CL
DUR-03-503-001	1-4	24	19	5	CL-ML
DUR-03-508-001	5-8	49	16	33	CL

Table 7.5 Gradation test results (D&M)

Boring number	Depth (feet)	No. 4	Percentage passing standard sieve sizes (%)				
			No. 8	No. 10	No. 40	No. 100	No. 200
B-1	46.5	100	99	98	98	96	87

Ref. Dames and Moore, 1983b.

Table 7.6 Gradation test results (TAC)

Sample No.	Depth interval (feet)	Percent passing standard sieve sizes (washed)						
		#4	#8	#16	#30	#50	#100	#200
DUR-03-500-001	4-8	100	99	98	97	96	94	90
DUR-03-502-001	1-4	---	100	98	97	96	96	84
DUR-03-508-001	5-8	100	98	96	95	94	93	90

Table 7.7 Hydrometer test results (TAC)

Sample No.	Depth interval (feet)	Percent passing hydrometer gradation (diameter (mm) or sieve size)						
		#200	0.037	0.019	0.009	0.005	0.002	0.001
DUR-03-500-001	4-8	90	76	59	49	44	39	36
DUR-03-503-001	1-4	84	58	42	27	24	21	19
DUR-03-508-001	5-8	90	81	73	64	58	52	47

Table 7.8 In-situ moisture content (TAC)

Sample number	Depth interval (feet)	Unified soil classification	Moisture (%)
DUR-03-500-001	4-8	CL	19.0
DUR-03-503-001	1-4	CL-ML	8.6
DUR-03-508-001	5-8	CL	22.8

Table 7.9 Specific gravity test results (D&M)

Boring or test pit number	Depth (feet)	Unified soil classification	Specific gravity
B-2	16.5	CH	2.89
B-2	36.5	CL	2.78
TP-10 & TP-11[a]	12.5 & 14.0	CH	2.77

[a]Bulk samples from test pits 10 and 11 were combined to perform this test.

Ref. Dames and Moore, 1983b.

Table 7.10 Specific gravity test results (TAC)

Sample Number	Depth interval (feet)	Unified soil classification	Specific gravity
DUR-03-500-001	4-8	CL	2.76
DUR-03-503-001	1-4	CL-ML	2.66
DUR-03-508-001	5-8	CL	2.71

Table 7.11 Permeability test results (D&M)

Boring or test pit number	Depth (feet)	Unified soil classification	Moisture (%)	Dry density (pcf)	Confining pressure (psf)	Permeability (cm/sec)
B-1	46.5	CL-ML	20.0	108	4,000	3.0×10^{-7}
B-1	46.5	CL-ML	20.0	108	8,000	9.7×10^{-9}

Tested samples were relatively undisturbed drive samples.

NOTES: pcf = pounds per cubic foot.
psf = pounds per square foot.
cm/sec = centimeters per second.

Ref. Dames and Moore, 1983b.

Table 7.12 Consolidation test results (D&M)

Boring or test pit number	Depth (feet)	Soil classi-fication	Initial moisture (%)	Initial dry density (pcf)	Final moisture (%)	Final dry density (pcf)	Preconsolidation pressure (psf)	Compression Index	
								Virgin	Rebound
B-2[a]	11.5	CH	22.9	102	25.5	104	31,000	0.257	.100
B-2[a]	36.5	CL	24.0	101	19.4	112	4,200	0.232	.045

[a]Tested samples were relatively undisturbed drive samples.

Ref. Dames and Moore, 1983b.

Table 7.13 Triaxial compression test results (unconsolidated-undrained) (D&M)

Boring or test pit number	Depth (feet)	Soil classification	Moisture (%)	Dry density (pcf)	Stresses at failure (PSF) Minor-principal stress	Stresses at failure (PSF) Major-principal stress	Cohesion (psf)
B-1	26.5	CL	24.3	98	4,000	10,668	3334
B-1	31.5	CL	16.8	113	4,000	14,306	5653
B-1	36.5	CL	18.7	107	8,000	10,910	1455
B-1	41.5	CL	21.9	104	12,000	14,148	1074

Tested samples were relatively undisturbed drive samples.

Ref. Dames and Moore, 1983b.

Table 7.14 Triaxial compression test results (consolidated-undrained) (D&M)

Boring or test pit number	Depth (feet)	Unified soil class.	Moisture (%)	Dry density (pcf)	Stresses at failure (psf)				Effective friction angle (degrees)	Effective cohesion (psf)
					Total minor-principal stress	Total major-principal stress	Effective minor-principal stress	Effective major-principal stress		
B-5	16.5	CL	19.0	110	5,000	14,480	3,370	12,850		
B-2	31.5	CL	19.5	110	10,000	21,840	4,170	16,010	30.5	825
B-1	51.5	CL	17.9	113	15,000	29,100	5,640	19,740		
B-6	6.0	CL	24.4	104	4,000	9,450	1,480	7,150		
B-6	11.5	CL	22.4	111	8,000	16,150	5,090	13,240	25.0	550
B-2	21.5	CH	18.9	114	12,000	28,140	8,400	24,540		

Tested samples were relatively undisturbed drive samples.

Ref. Dames and Moore, 1983b.

Table 7.15 Field shear strength of fine-grained soils[a] (D&M)

Boring number	Depth (feet)	USCS classification	Undrained shear strength[b] (psf)
B-1	21.5	CL	2200[c]
	31.5	CL	3000[c]
	36.5	CL	3500[c]
	41.5	CL	3500[c]
	51.5	CL	400
	61.5	ML	800
B-2	36.5	CL	800
	41.5	ML	400
	46.5	ML	600
	51.0	CL-ML	1200
B-3	11.0	CL-ML	1700
B-5	6.5	CL	1700
	9.0	CL	1700
	11.5	CL	1800
	16.5	CL	1200
	21.5	CL	1100
B-6	6.0	CL	>2000
	11.5	CL	>2000
	16.5	CL-ML	>2000
	21.5	CL	>2000
	26.0	CL-ML	1600
	31.5	CL-ML	1400

[a]Approximate value of undrained shear strength obtained by testing fine-grained soils with a pocket penetrometer or Torvane.

[b]Undrained shear strength determined using Torvane except where noted in Boring B-1. Undrained shear strengths listed with the symbol ">" preceding the tabulated value indicate the sample shear strength exceeded the 2000 psf upper measuring limit of the Torvane.

[c]Undrained shear strength determined using pocket penetrometer.

Ref. Dames and Moore, 1983b.

Table 7.16 Atterberg limits test results (D&M)

Test pit number	Depth (feet)	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	Unified soil classification
TP-4	4-4.5	35	20	15	CL
TP-4	11-12.5	38	22	16	CL

Table 7.17 In-situ moisture content

Test pit number	Depth (feet)	Unified soil classification	Moisture (%)
TP-4	4.0-4.5	CL	15.9
TP-4	11.5-12	CL	18.0

Table 7.18 Compaction test results (D&M)

Test pit[a] number	Depth (feet)	Maximum dry density (pcf)	Optimum moisture (%)
TP-4	4.0-4.5	119	12.4
TP-4	11.5-12.0	118	14.8

[a]Compaction tests were performed on bulk samples.

NOTES:
The compaction tests were performed in accordance with American Society for Testing and Materials (ASTM) method D1557.
pcf = pounds per cubic foot.

Ref. Dames and Moore, 1983b.

Table 7.19 Permeability test results (D&M)

Boring or test pit number	Depth (feet)	Soil classification	Moisture (%)	Dry density (pcf)	Confining pressure (psf)	Permeability (cm/sec)
TP-4	11.5-12	CL	19.7	120	1,000	1.0×10^{-9}
TP-4	11.5-12	CL	19.7	120	5,000	1.9×10^{-8}
TP-4	11.5-12	CL	19.7	120	10,000	1.0×10^{-10}

Tested samples were bulk samples remolded to approximately 90 percent ASTM D1557.

NOTES:
pcf = pounds per cubic foot.
psf = pounds per square foot.
cm/sec = centimeters per second.

Ref. Dames and Moore, 1983b.

Table 7.20 Consolidation test results (D&M)

Boring or test pit number	Depth (feet)	Soil classification	Initial moisture (%)	Initial dry density (pcf)	Final moisture (%)	Final dry density (pcf)	Preconsolidation pressure (psf)	Compression Index	
								Virgin	Rebound
TP-4	4.0-4.5	CL	14.5	116	19.5	115	43,000	0.113	.075

Tested materials were bulk samples remolded to approximately 90 percent ASTM D1557.

Ref. Dames and Moore, 1983b.

Table 7.21 Compaction test results (D&M)

Test pit[a] number	Depth (feet)	Maximum dry density (pcf)	Optimum moisture (%)
TP-10	4.0	120	12.5
TP-10 & TP-11[b]	12.5 & 14.0	113	15.2

[a]Compaction tests were performed on bulk samples.
[b]Samples from test pits 10 and 11 were combined.

NOTES:
The compaction tests were performed in accordance with American Society for Testing and Materials (ASTM) method D1557 (modified Proctor)
pcf = pounds per cubic foot.

Ref. Dames and Moore, 1983b.

Table 7.22 Compaction test results (TAC)

Sample number	Depth interval (feet)	Maximum dry density (pcf)	Optimum moisture (%)
DUR-03-500-001	4-8	101.7	19.8
DUR-03-503-001	1-4	113.4	12.9
DUR-03-508-001	5-8	100.2	22.0

Note: Compaction tests were performed in accordance with ASTM method D698 (standard Proctor).

Table 7.23 Triaxial backpressure saturated permeability test results[a] (TAC)

Sample Number	Depth interval (feet)	Unified soil classification	Moisture content (%)	Dry density (pcf)	Effective consolidation pressure (psf)	Permeability (centimeters/second)
DUR-03-500-001	4-8	CL	21.8	97.5	403	1.8×10^{-7}
DUR-03-503-001	1-4	CL-ML	15.0	108.7	403	7.7×10^{-6}
DUR-03-508-001A	5-8	CL	23.6	95.7	403	2.9×10^{-8}
DUR-03-508-001B	5-8	CL	27.7	96.9	3000	3.9×10^{-9}
DUR-03-508-001C	5-8	CL	26.7	98.3	6000	1.9×10^{-9}

[a]Tests performed on samples that were compacted to 95% of standard Proctor maximum density.

Table 7.24 Capillary moisture test results (TAC)

Sample number[a]	Depth interval (feet)	Moisture content (%)	Dry density (pcf)	Water retention (%)					
				Capillary tension (bars): 1	2	4	7	10	15
DUR03-500-001	4-8	20.8	97.6	22.4	21.7	20.9	20.2	19.9	19.5
DUR03-503-001	1-4	14.9	108.2	16.2	15.8	15.3	15.0	14.8	14.1
DUR03-508-001	5-8	24.1	95.7	26.3	25.2	24.6	24.0	23.6	23.0

[a]Tests performed on samples remolded to 95 percent of standard Proctor maximum density.

Table 7.25 Calculated values of unsaturated hydraulic conductivity for recompacted site soils

Sample number	Depth (feet)	Unified soil classification	Dry density (pcf)	Saturation (%)	Unsaturated hydraulic conductivity (cm/sec)
DUR03-500-001	4-8	CL	97.6	100	1.8×10^{-7}
				97	2.3×10^{-8}
				94	3.6×10^{-9}
				91	8.9×10^{-10}
				88	1.9×10^{-10}
				85	4.3×10^{-11}
				82	6.6×10^{-12}
				79	8.9×10^{-13}
				76	1.9×10^{-13}
				73	4.3×10^{-15}
DUR03-503-001	1-4	CL-ML	108.2	100	7.3×10^{-3}
				97	6.8×10^{-4}
				94	9.6×10^{-5}
				92	3.5×10^{-5}
				89	8.6×10^{-6}
				86	1.6×10^{-6}
				83	1.9×10^{-7}
				81	1.6×10^{-8}
				78	1.3×10^{-9}
				75	5.3×10^{-9}
DUR03-508-001	5-8	CL	95.7	100	2.7×10^{-8}
				98	1.8×10^{-9}
				96	4.6×10^{-10}
				94	1.8×10^{-10}
				93	6.8×10^{-11}
				91	1.8×10^{-11}
				89	3.9×10^{-12}
				87	5.4×10^{-13}
				85	1.4×10^{-13}
				83	1.4×10^{-14}

Table 7.26 Consolidation test results (D&M)

Boring or test pit number	Depth (feet)	Soil classification	Initial moisture (%)	Initial dry density (pcf)	Final moisture (%)	Final dry density (pcf)	Preconsolidation pressure (psf)	Compression index	
								Virgin	Rebound
TP-10[a]	4.0	CL	11.8	111	17.5	118	20,000	0.20	.035
TP-10[a,b]	12.5								
&	&	CH	16.4	114	21.6	112	35,000	0.153	.080
TP-11	14.0								

[a]Tested materials were bulk samples remolded to approximately 90 percent of modified Proctor maximum density.
[b]Bulk samples from test pits 10 and 11 were combined to perform this test.

Ref. Dames and Moore, 1983b.

Table 7.27 Consolidation test results (TAC)

Sample number[a]	Depth interval (feet)	Unified soil classification	Initial moisture (%)	Initial dry density (pcf)	Final moisture (%)	Final dry density (pcf)	Preconsolidation pressure (psf)	Compression index	
								Virgin	Rebound
DUR-03-500-001	4-8	CL	21.7	97.4	19.7	111.3	2200	.233	.030
DUR-03-503-001	1-4	CL	15.0	106.9	19.5	107.8	8000	.107	.011

[a]Samples tested were remolded to approximately 95 percent of standard Proctor maximum density.

Table 7.28 Triaxial compression test results (unconsolidated-undrained) (D&M)

Boring or test pit number	Depth (feet)	Soil classification	Moisture (%)	Stresses at failure (PSF)			Cohesion (psf)
				Dry density (pcf)	Minor-principal stress	Major-principal stress	
TP-10 & 11	12.5-14.0	CH	19.5	110	2,000	15,790	6895
TP-10 & 11	12.5-14.0	CH	18.1	110	4,000	19,996	7998
TP-10 & 11	12.5-14.0	CH	16.9	110	8,000	33,240	12,620
TP-10 & 11	12.5-14.0	CH	16.1	110	12,000	36,668	12,334

Tested bulk samples were remolded to approximately 90% of standard Proctor maximum density bulk samples from test pits 10 and 11 were combined to perform this test.

Ref. Dames and Moore, 1983b.

Table 7.29 Triaxial Compression Test Results (unconsolidated - undrained)[a] (TAC)

Sample number	Depth interval (feet)	Unified soil classification	Moisture (%)	Dry density (pcf)	Stresses at failure (psf)		Cohesion (psf)
					Total minor principal stress	Total major principal stress	
DUR03-508-001	5-8	CL	23.2	95.7	1000	4760	1880
DUR03-508-001	5-8	CL	23.4	96.1	3000	7720	2360
DUR03-508-001	5-8	CL	23.0	96.2	6000	10830	2415

[a]Samples tested were remolded to approximately 95% of standard Proctor maximum density.

Table 7.30 Triaxial compression test results (consolidated-undrained) (D&M)

					Stresses at failure (psf)					
Boring or test pit number	Depth (feet)	Unified soil class.	Moisture (%)	Dry density (pcf)	Total minor-principal stress	Total major-principal stress	Effective minor-principal stress	Effective major-principal stress	Effective friction angle (degrees)	Effective cohesion (psf)
TP-10 & 11	12.5 & 14	CH	23.5	107	4,000	7,990	10	4,410		
TP-10 & 11	12.5 & 14	CH	22.8	108	8,000	15,730	4,620	12,350	18.0	2225
TP-10 & 11	12.5 & 14	CH	21.2	109	12,000	22,450	6,930	17,380		

Bulk samples from test pits 10 and 11 were combined to perform this test; tested bulk sample was remolded to approximately 90 percent ASTM D1557

Ref. Dames and Moore, 1983b.

Table 7.31 Triaxial compression test results (consolidated - undrained)[a] (TAC)

Sample number	Depth interval (feet)	Unified soil class.	Moisture (%)	Dry density (pcf)	Stresses at failure (4% strain) (psf): Total minor-principal stress	Total major-principal stress	Effective minor-principal stress	Effective major-principal stress	Effective friction angle (degrees)	Effective cohesion (psf)
DUR03-500-001	4-8	CL	22.0	97.8	1000	2180	1580	400		
DUR03-500-001	4-8	CL	22.3	97.6	3000	5490	3880	1400	22.5	300
DUR03-500-001	4-8	CL	22.4	97.6	6000	10270	7160	2890		
DUR03-503-001	1-4	CL	15.0	107.5	994	2366	504	1876		
DUR03-503-001	1-4	CL	15.0	107.8	2995	5774	1166	3945	31.6	100
DUR03-503-001	1-4	CL	15.0	109.1	6004	13399	3196	10592		

[a] Samples tested were remolded to approximately 95 percent of standard Proctor maximum density.

Table 7.32 Pinhole dispersion tests results (D&M)

Boring or test pit number	Depth (feet)	Unified soil classification	Soil dispersivity classification[a]
TP-4[b]	4.0-4.5	CL	ND-2
B-2[c]	16.5	CH	ND-1

[a]Soil Conservation Service dispersibility designation, ND-1 and ND-2 indicate nondispersive soil.
[b]Tested bulk sample remolded to approximately 90 percent ASTM D1557.
[c]Tested sample was relatively undisturbed drive sample.
Tests Performed in accordance with Soil Conservation Service methods.

Table 7.33 Dispersion Test Results (TAC)

Sample number	Depth (feet)	Unified soil classification	Dispersion test[a]
			Double Hydrometer: Percent dispersion
DUR03-503-001	1-4	CL-ML	91.7
			Pinhole Test: Dispersive rating[b]
DUR03-503-001	1-4	CL-ML	D_1
			Crumb Test: Dispersive rating
DUR03-503-001	1-4	CL-ML	Dispersive

[a]Samples tested were recompacted to 95 percent of standard Proctor maximum density.

[b]A dispersive rating of D_1 indicates a dispersive soil.

Table 7.34 Soil dispersivity test results (TAC)
(4% lime added)

Sample number[a]	Double hydrometer (% dispersion)	Pinhole test (dispersive rating)	Crumb test (dispersive rating)
DUR03-508-001[b]	13.7	ND_1[c]	non-dispersive

[a]Samples tested were blended with 4 percent lime then recompacted to 95 percent of standard Proctor maximum density.

[b]Low plasticity clay (CL) from a depth of 5 to 8 feet.

[c]A dispersive rating of ND_1, indicates a non-dispersive soil.

Table 7.35 Results of Atterberg limits, compaction, and permeability tests

Sample number	Depth interval (feet)	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	Unified soil class.	Compaction test[a] Maximum dry density (pcf)	Compaction test[a] Optimum moisture content (%)	Triaxial[b] permeability (centimeters/second)
DUR03-500-001	4-8	39 (36)	22 (17)	17 (19)	CL (CL)	99.9 (101.7)	21.4 (19.8)	-----
DUR03-503-001	1-4	19 (24)	23 (19)	NP (5)	ML (CL-ML)	107.6 (113.4)	5.5 (12.9)	-----
DUR03-508-001	5-8	42 (49)	22 (16)	20 (33)	CL (CL)	95.1 (100.2)	25.2 (22.0)	1.7×10^{-6} (1.2×10^{-8})

[a]Performed according to ASTM D698.
[b]Tests performed on samples that were blended with 4 percent lime then recompacted to 95 percent of standard Proctor maximum density.
( )Numbers in parentheses indicate values from similar tests on samples without lime.

Table 7.36 Capillary moisture test results (TAC)

Sample number	Depth interval (feet)	Moisture content (%)	Dry density (pcf)	Water rentention (%) Capillary tension (bars)					
				1	2	4	7	10	15
DUR03-500-001	4-8	23.6	95.2	26.1	25.4	24.7	24.1	23.6	23.2
DUR03-503-001	1-4	17.9	102.2	19.8	19.3	19.0	18.5	18.4	17.7
DUR03-508-001	5-8	28.4	90.1	31.0	30.0	29.4	28.6	28.3	27.9

Table 7.37 Estimated long-term moisture content of radon barrier soil

Sample number	Depth (feet)	Soil description	Specific gravity	Maximum[a] dry density (pcf)	Optimum moisture content (%)	Long-term[b] moisture content (%)
DUR03-500-001	4-8	Sandy silty clay (CL)	2.76	101.7	19.8	19
DUR03-503-001	1-4	Sandy silty clay (CL)	2.66	113.4	12.9	14
DUR03-508-001	5-8	Sandy silty clay (CL)	2.71	100.2	22.0	23

[a]Tested according to ASTM D698.
[b]Assuming cover originally compacted to 95 percent of standard Proctor maximum density at about 2 percent wet of optimum moisture content.

Table 7.38 Radon diffusion coefficients of on-site radon barrier soils

Sample number	Depth (feet)	Unified soil classification	Percent of standard Proctor maximum dry density	Porosity (fractional)	Moisture content (%)	Saturation (%)	Radon diffusion coefficient (cm^2/s)
DUR03-500-001	4-8	CL	96	0.43	12.3	44	2.2×10^{-2}
			95	0.44	13.1	46	1.8×10^{-2}
			101	0.40	13.8	57	2.0×10^{-2}
			96	0.43	15.9	57	1.0×10^{-2}
			94	0.44	17.5	61	1.2×10^{-2}
			93	0.45	19.5	66	3.1×10^{-3}
			96	0.43	20.1	73	1.4×10^{-3}
			96	0.43	20.8	75	1.7×10^{-3}
			96	0.43	20.8	75	3.7×10^{-4}
			101	0.40	21.7	90	7.8×10^{-4}
DUR03-503-001	1-4	CL-ML	95	0.35	6.5	32	1.2×10^{-2}
			95	0.35	6.6	33	8.7×10^{-3}
			95	0.35	7.1	35	9.0×10^{-3}
			95	0.35	10.4	51	7.2×10^{-3}
			98	0.33	10.6	57	5.2×10^{-3}
			95	0.35	11.6	56	5.2×10^{-3}
			94	0.36	13.7	65	1.8×10^{-4}
			95	0.35	14.2	70	1.7×10^{-3}
			96	0.35	14.3	72	2.9×10^{-4}

Ref. Nielson, 1984.

Table 7.39 Los Angeles abrasion test results (D&M)
(rock samples from quarry #2)

Sample designation	Drum revolutions	Material loss (%)
Quarry #2	200	13.7
Quarry #2	1000	41.7

NOTE: Tests performed in accordance with ASTM C535.

Ref. Dames and Moore, 1983b.

Table 7.40 Sodium sulfate soundness tests results (D&M)
(rock samples from quarry #2)

U.S. standard sieve size	Weight of test fraction before test (grams)	Percentage passing designated sieve after test (%)	Weighted percentage loss (%)
1-1/2" to 1"	1012	0.00	0.00
1" to 3/4"	503	0.00	0.00
3/4" to 1/2"	675	0.00	0.00
1/2" to 3/8"	327	0.61	0.03
3/8" to N.4	300	5.00	0.25
Totals	2817	5.61	0.28

NOTES: Sample from Quarry No. 2.
Tests performed in accordance with the ASTM C88-76.

Ref. Dames and Moore, 1983b.

Table 7.41 Los Angeles abrasion and sodium soundness test results (TAC) (slag samples from Durango processing site)

Sample designation	Los Angeles abrasion (% wear) ASTM C131 (at 500 revolutions)	Los Angeles abrasion (% wear) ASTM C535 (at 1000 revolutions)	Sodium soundness (weighted % loss after 5 cycles)
Durango slag	21	23	0.2

8.0 METEOROLOGICAL DATA

8.1 WEATHER PATTERNS

The climatic zone of southwestern Colorado can be termed as a highland or mountain climate that is temperate and semi-arid. It is characterized by warm summers, cool springs and autumns, and moderately cold winters. In general, precipitation is distributed evenly throughout the year.

The Durango area is often affected by well-developed weather systems approaching from the north or west during the cooler months and by local thunderstorms during the summer months. Rapid changes in topographic relief in the immediate vicinities of Durango and the Bodo Canyon site influence the wind and temperature patterns at these locations which, in turn, influence the wind dispersion characteristics of these areas (DOE, 1984).

8.2 WINDS

Wind speeds and directions were measured in Bodo Canyon from February, 1982, through January, 1983. The wind speed frequency distribution by direction and graphical windroses for the Bodo Canyon site are presented in Table 8.1 and Figure 8.1. During 1982, the annual average wind speed in Bodo Canyon was 5.3 miles per hour. Calm conditions (less than 1 mile per hour), with poor dispersion characteristics, occurred about 1.0 percent of the time. The predominant wind direction of Bodo Canyon was

from the west-southwest about 15 percent of the time. Winds at the Bodo Canyon site are fairly evenly distributed in all directions because of the lack of channeling through the broader Bodo Canyon area.

8.3 TEMPERATURE

During 1982, a meteorological monitoring station was operated at the Bodo Canyon disposal site. Extreme daily average minimum and maximum temperatures recorded at this station ranged from 18.1°F to 84.4°F while the annual average temperature was 48.4°F.

Normally, about 18 days out of the year the temperatures can be expected to reach or exceed 90°F while the temperatures will reach 0°F or below for only 10 days out of the year (NOAA, 1981). A summary of temperatures recorded at the monitoring stations is listed in Table 8.2.

8.4 PRECIPITATION

Site-specific precipitation measurements are not available for the Bodo Canyon disposal site; however, the precipitation patterns for these sites are similar to the long-term patterns established at the Durango-La Plata County Airport. The annual average precipitation measured at the airport over a 23-year period was 18.69 inches. The highest average monthly precipitation was 2.66 inches in August, while June had the least

with 0.75 inches. Snow can occur from October through May, with December and January experiencing the greatest average snowfalls of 46 and 58 inches, respectively. On the average, only 11 days out of the year experience 0.5 inch or more of precipitation (rain or snow), and only one day of the year is likely to have 1 inch or more of precipitation (Miller et al., 1973).

It is estimated that about 15 intense thunderstorms can be expected in the Durango area each summer. According to Miller et al. (1973), during the warmer months lasting from May through October, there is a 50 percent probability that 0.6 inch of rain will occur in a one-hour period and 1.0 inch will occur in a period of 6 hours; however, there is only a 10 percent probability of a 6-hour rainfall yielding 2.2 inches of rain.

8.5 FROST

The average annual frost-free period at Durango is 121 days starting in May and lasting through September (NOAA, 1981). Extreme frost penetration for the Durango area up to an elevation of 8,000 feet for the period 1975 to 1983 was 20 inches (SCS, 1982).

8.6 EVAPORATION

The mean annual evaporation rate for Durango based on the period 1946 to 1955 was approximately 48 inches. Seventy-five percent of this total occurs during the months of May through October (NOAA, 1981).

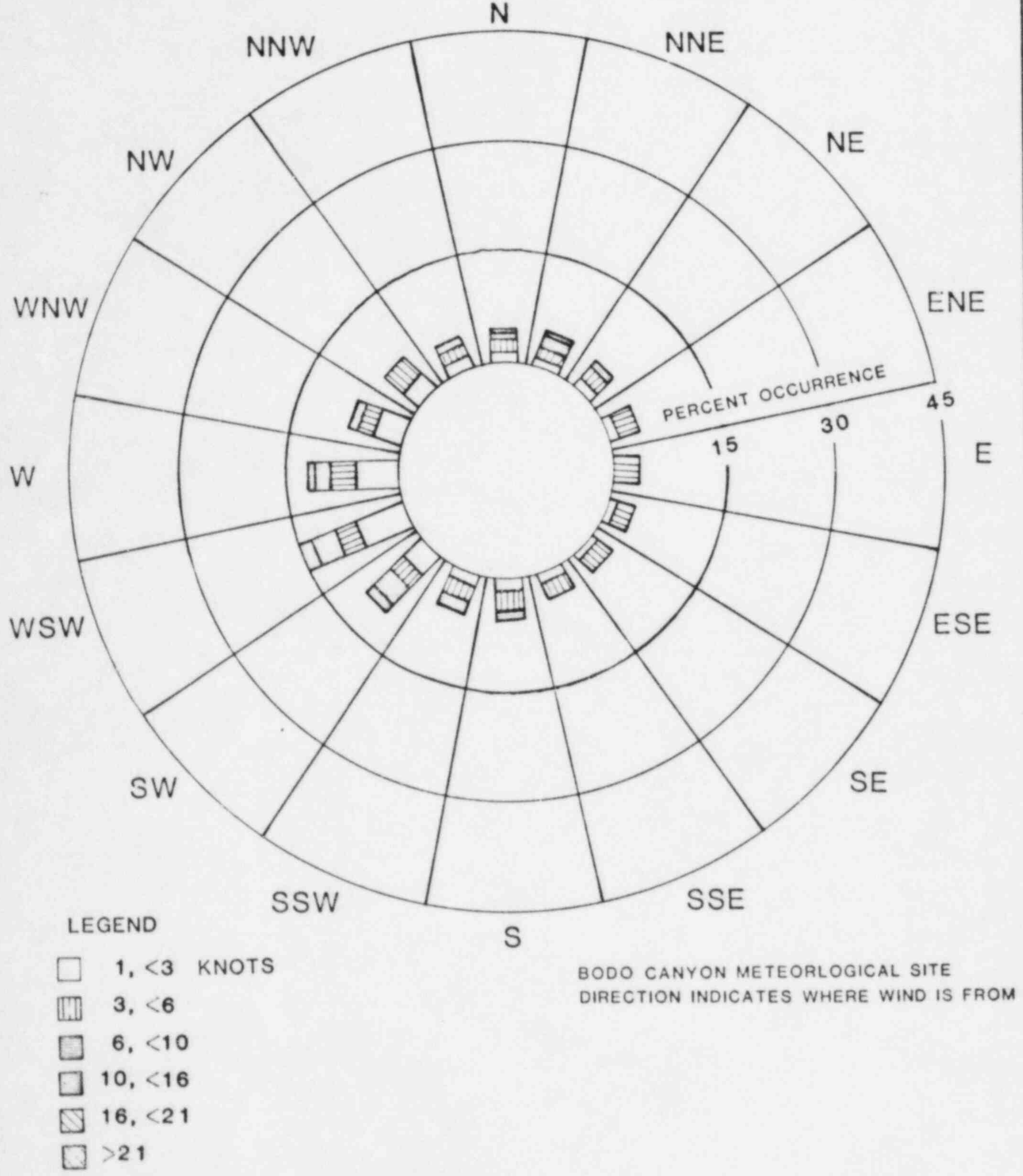


FIGURE 8.1
FREQUENCY OF WINDS (%) BY DIRECTION AND SPEED FEBRUARY 1982 - FEBRUARY 1983

Table 8.1 Wind frequency distribution - Bodo Canyon site February, 1982, through December, 1983 (by percent)

Wind direction	Upper class intervals of wind speed (knots)[a] 3	6	10	16	21	>21	Total
N	2.0	1.6	1.1	0.2	0.0	0.0	4.9
NNE	1.6	1.4	1.6	0.7	0.0	0.0	5.2
NE	1.5	2.2	0.9	0.2	0.0	0.0	4.8
ENE	1.1	2.7	0.5	0.0	0.0	0.0	4.4
E	0.6	2.5	0.3	0.0	0.0	0.0	3.4
ESE	0.7	2.1	0.2	0.0	0.0	0.0	3.0
SE	0.8	2.3	0.3	0.0	0.0	0.0	3.5
SSE	1.4	1.8	0.5	0.0	0.0	0.0	3.7
S	1.5	2.8	1.3	0.0	0.0	0.0	5.6
SSW	1.3	2.3	1.6	0.5	0.0	0.0	5.7
SW	3.3	2.5	3.4	1.1	0.1	0.0	10.5
WSW	6.5	3.0	3.4	2.0	0.1	0.0	15.0
W	5.5	3.4	2.1	1.0	0.0	0.0	12.1
WNW	3.6	2.6	1.0	0.2	0.0	0.0	7.4
NW	3.0	2.4	0.6	0.1	0.0	0.0	6.0
NNW	2.2	1.7	0.8	0.1	0.0	0.0	4.8
All	36.6	37.3	19.8	6.1	0.2	0.0	100.0

[a]All calms distributed.

NOTES: Total number of invalid observations = 938.
Total number of valid observations = 7640.
Data recovery rate = 89.0 percent.

Ref. DOE, 1984.

Table 8.2 Temperature summary for 1982 - Bodo Canyon site

Month	Average daily maximum °F	Average daily minimum °F	Daily average °F	Monthly maximum °F	Monthly minimum °F
Jan	37.2	18.6	27.0	51.1	8.1
Feb	44.1	23.1	33.2	62.2	14.0
Mar	50.0	27.2	38.3	66.4	14.0
Apr	62.3	35.1	49.1	75.3	22.1
May	70.1	41.2	56.0	85.8	29.2
Jun	NA	NA	NA	NA	NA
Jul	84.4	56.8	71.2	74.6	48.7
Aug	82.2	57.1	69.1	94.7	50.6
Sep	75.6	49.5	61.0	75.5	36.4
Oct	59.0	33.0	45.6	74.2	23.3
Nov	50.1	27.1	38.5	67.1	15.2
Dec	44.2	21.9	32.7	62.0	-1.1
Annual	61	34	48	94	-1

[a]NA indicates not available; date either missing or invalid.

Ref. DOE, 1984.

9.0 MISCELLANEOUS DATA

9.1 LAND USE

The Bodo Canyon site is owned by the State of Colorado as a part of the 8000-acre Bodo Canyon Wildlife area for open space, wildlife conservation, and camping (Figure 9.1). The Bodo Canyon site is not committed to future land uses although over one-half of the refuge to the south and west will be impacted by the proposed Animas-La Plata Water Resource Project as shown in Figure 9.1.

An estimated 14,695 people reside within 5 miles of the Bodo Canyon site; however, the immediate area is uninhabited. The closest residents live about one to two miles to the west of the site. The largest number, about 11,000, live four miles to the north of the site in Durango.

9.2 ARCHAEOLOGICAL, HISTORICAL, OR CULTURAL SITES

An intensive cultural resource inventory of the Bodo Canyon site and vicinity conducted in October 1981 (Dames and Moore, 1983b), resulted in the identification of 24 prehistoric sites and 10 isolated artifacts. The transportation corridor, County Roads 211 and 212, was inventoried by Complete Archaeological Services Associates (CASA) in 1984 (Hammack, 1985). Based on these inventories, the Colorado Historic Preservation Office determined that nine sites are eligible for nomination to the National

Register of Historic Places (NRHP). Only seven of the sites are within the potential area of disturbance if the alternative for relocation to the Bodo Canyon disposal site is implemented. CASA has developed a data recovery plan to mitigate impacts to the seven potentially impacted archaeological sites, and will proceed with that recovery plan upon approval by the DOE.

9.3 COMMUNITY SERVICES

Police protection is provided to the unincorporated areas in the County by the La Plata County Sheriff's Department. Additionally, the Colorado Division of Wildlife patrols the Bodo Canyon area. Fire protection is provided by the Animas Fire Protection District through a mutual aid agreement with the Colorado Department of Wildlife.

Medical service is available from the La Plata Community Hospital or the 100-bed Mercy Medical Center, which would also provide ambulance service. Emergency service can be requested by calling 911.

Public education in La Plata County is provided by three school districts, headquartered in Durango, Bayfield, and Ignacio. The largest district, Durango School District 9-R, had a total of 3764 students in November 1981, compared to 3638 in 1980, and 3694 in 1979. The Durango school district is operating below capacity. Other education resources in the area include three private grade schools, a private high school, and Fort Lewis College (DOE, 1984).

There are three solid waste disposal areas in La Plata County: one in the Red Mesa Area, one near Bayfield on County Road 223, and the main landfill just west of Durango off U.S. Highway 160 (DOE, 1984).

9.4 UTILITIES

Electricity is available on the site from Colorado Ute Electric Association. Present service is limited to 220 volts. There is no natural gas service to the site. Bottled gas is available from Basin Petroleum Company, Basin Co-Op, Inc., or Buckeye Gas Products Company, Durango. Telephone service is available on the site from Mountain Bell. There is no developed water supply or sewage treatment facility on the site. The nearest connections are about 2 miles east of the site in the Bodo Industrial Park.

9.5 TRANSPORTATION

Transportation routes between the Durango tailings site and the Bodo Canyon alternate disposal site are shown in Figure 9.2. Current traffic volume data do not exist for County Road 211. Traffic counts in 1982 indicated volumes on U.S. Highway 550 ranged from 12,500 to 14,600 average daily trips (ADT) at counter locations near the Durango site and 8650 ADT's on U.S. Highway 160 near the junction with U.S. Highway 550 (DOE, 1984). The accident rate for the combined segment of U.S. Highways 160 and 550 in 1983 was 7.94 accidents per million vehicle miles with no fatalities recorded (Colorado State Highway Department, 1984).

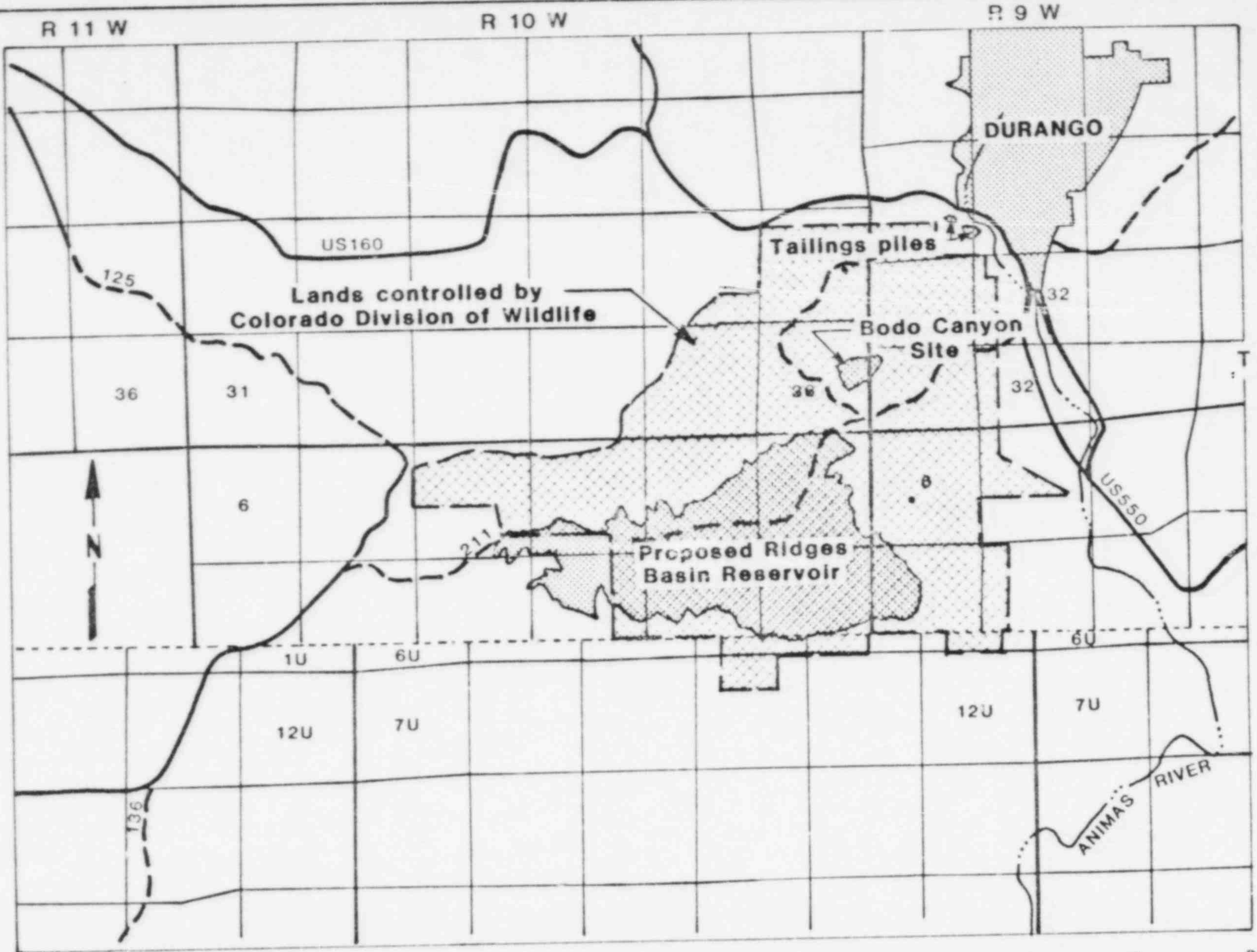


FIGURE 9.1
LAND USE IN THE BODO CANYON AREA

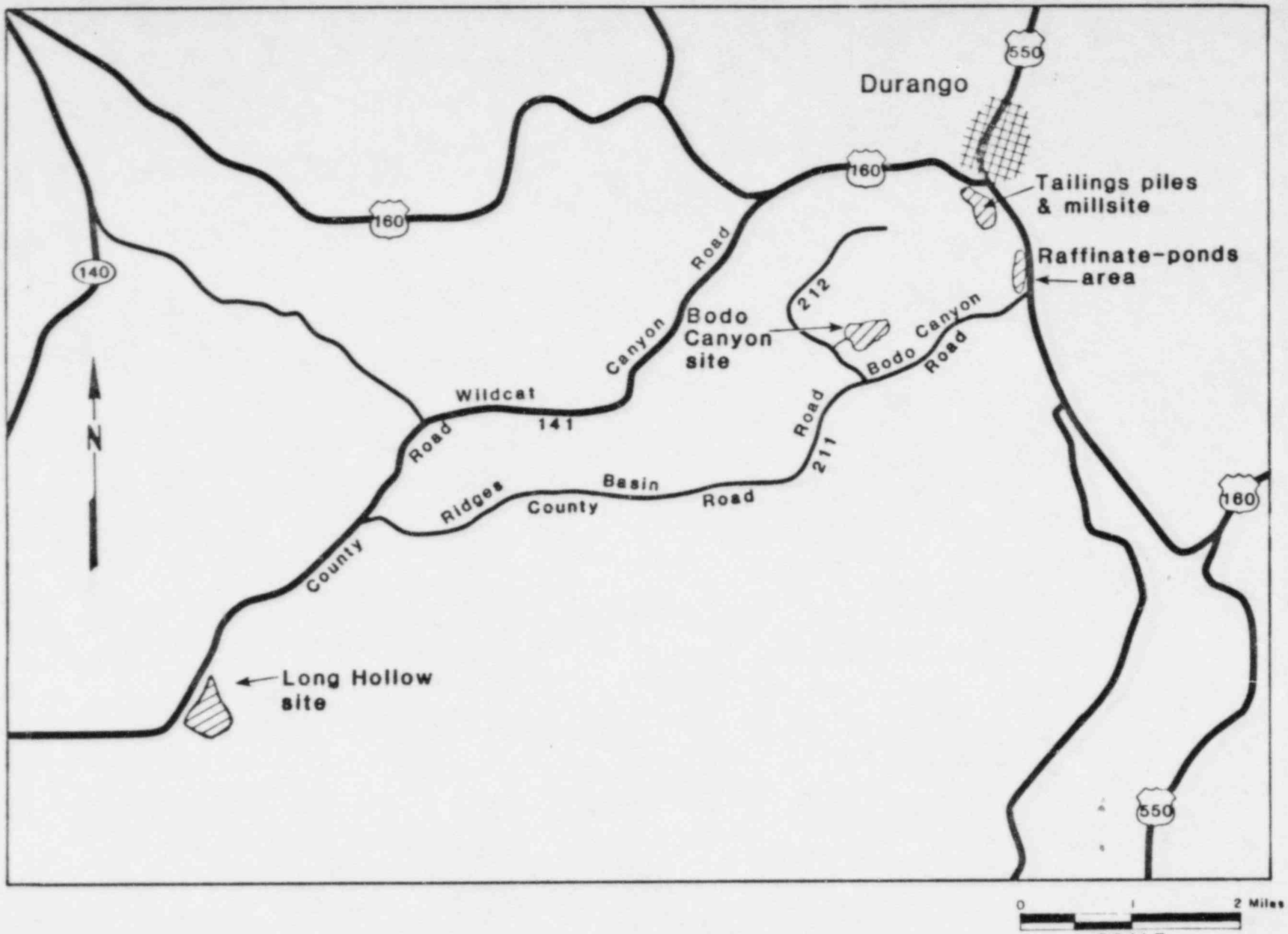


FIGURE 9.2
TRANSPORTATION NETWORKS

10.0 ONGOING DATA NEEDS

Land survey data

A boundary survey and legal description of the site as well as a verification of ownership and easements are required if Bodo Canyon is the selected disposal site. The U.S. Army Corps of Engineers is presently performing an appraisal of the Bodo Canyon site for purposes of acquisition, should the site be selected as the disposal site. Part of their appraisal includes a survey and legal description.

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