UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

SITE EVALUATION FOR U.S. BUREAU OF MINES EXPERIMENTAL OIL-SHALE MINE, PICEANCE CREEK BASIN, RIO BLANCO COUNTY, COLORADO

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By

John R. Ege, George H. Leavesley,
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CONTENTS

ILLUSTRATIONS

TABLES

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ABSTRACT

The U.S. Geological Survey is cooperating with the U.S. Bureau of Mines in the selection of a site for a shaft and experimental mine to be constructed in the Piceance Creek basin, Rio Blanco County, Colo.

The Piceance Creek basin, an asymmetric, northwest-trending large structural downwarp, is located approximately 40 km (25 mi) west of the town of Meeker in Rio Blanco County, Colo. The oil-shale, dawsonite, nahcolite, and halite deposits of the Piceance Creek basin occur in the lacustrine Green River Formation of Eocene age. In the basin the Green River Formation comprises three members. In ascending order, they are the Douglas Creek, the Garden Gulch, and the Parachute Creek Members.

Four sites are presented for consideration and evaluated on geology and hydrology with respect to shale-oil economics. Evaluated criteria include: (1) stratigraphy, (2) size of site, (3) oil-shale yield, (4) representative quantities of the saline minerals dawsonite and nahcolite, which must be present with a minimum amount of halite, (5) thickness of a "leached" saline zone, (6) geologic structure, (7) engineering characteristics of rock, (8) representative surface and ground-water conditions, with emphasis on waste disposal and dewatering, and (9) environmental considerations.

Serious construction and support problems are anticipated in sinking a deep shaft in the Piceance Creek basin. The two major concerns will be dealing with incompetent rock and large inflow of saline ground water, particularly in the leached zone. Engineering support problems will include stabilizing and hardening the rock from which a certain amount of ground water has been removed.

The relative suitability of the four potential oil-shale experimental shaft sites in the Piceance Creek basin has been considered on the basis of all available geologic, hydrologic, and engineering data; site 2 is preferred to sites 1, 3, and 4.

The units in this report are presented in the form: metric (English). Both units of measurement are necessary as measurements were taken in English units, and most of the contracting agencies involved are using predominantly English units.

METRIC CONVERSION

English units used in this report may be converted to metric units by the following conversion factors:

English	Multiply by	Metric
inches	25.4	millimeters (mm)
feet	.3048	meters (m)
miles	1.609	kilometers (km)
square miles	2.590	square kilometers (km^2)
acre-feet	.001233	cubic hectometers (hm^3)
pounds per cubic foot	16.02	kilograms per cubic meter (kg/m^3)
gallons per ton	3.785	liters per ton (L/ton)
barrels per day	.1590	cubic meters per day (m^3/d)
tons per day	.9072	tonnes per day (t/d)
cubic feet per second	.02832	cubic meters per second (m^3/s)
feet squared per day	.0929	meters squared per day (m^2/d)
acres	2.47	hectares
lb/in^2	.0069	Megapascal (MPa)

GEOLOGIC EVALUATION

By

John R. Ege and Susan G. Steele

INTRODUCTION

At the request of the USBM (U.S. Bureau of Mines), the USGS (U.S. Geological Survey) is cooperating in the selection of a site for an experimental shaft and mine to be constructed in the oil shale of the Piceance Creek basin, Rio Blanco County, Colo. The purpose of the shaft and mine is to develop and test mining techniques in a typical underground environment that would be representative of a commercial shale-oil recovery site. In addition to shale-oil development, consideration will be given to aluminum and sodium bicarbonate recovery from dawsonite and nahcolite deposits disseminated throughout the rich oil-shale zones underlying the dissolution surface.

USGS technical assistance is divided into two phases. Phase I involved preliminary investigations of potential sites that satisfy the following general criteria:

1. Overburden to top of Mahogany zone (245-365 m (800-1,200)).
2. Size of site (1,000-2,000 ha (2,470-4,940 acres)).
3. Continuous oil-shale section at least 150-300 m (about 500-1,000 ft) thick that averages 70 L/ton (20 gal/short ton) and lies between the dissolution surface and the base of the R-2 oil-shale zone. The section should also contain representative quantities of the minerals dawsonite and nahcolite and minimum amounts of halite.
4. A thickness of about 120 (400 ft) of the leached saline zone that lies below the Mahogany zone.
5. Representative salinity, hydraulic conductivity, and transmissivity of general surface and ground-water conditions.
6. No areas containing major fault or fracture systems.

Phase II of USGS technical assistance entailed core drilling and analyses, inhole hydrologic testing, geophysical logging, and environmental investigations.

GEOLOGY

The Piceance Creek basin, an asymmetric, northwest-trending large structural downwarp that lies west of Meeker in Rio Blanco County, Colo., contains oil shale, dawsonite, halite, and nahcolite in the Green River Formation.

The lacustrine Green River Formation of Eocene age underlies large areas of the Uinta, Green River, Washakie, Piceance Creek, and Sand Wash basins of northeastern Utah, southwestern Wyoming, and northwestern Colorado. In the basin the Green River Formation comprises three members. In ascending order, they are the Douglas Creek, the Garden Gulch,and the Parachute Creek Members. The Parachute Creek Member is overlain by the Uinta Formation. The Douglas Creek consists of sandstone and minor amounts of algal and oolitic limestone; the Garden Gulch is mainly clay shale and low- to moderate-grade oil shale that grades into richer oil shale at the basin center; the Parachute Creek is almost entirely low-grade to rich oil shale that contains thin analcimized tuff beds and thin sandstone beds, finely disseminated dawsonite, pods of nahcolite, and beds of halite and nahcolite (Donnell and Blair, 1970). The Uinta Formation consists of a transitional sequence of sandstones, siltstones, and marlstones that grade upward into predominantly massive brown medium- to coarse-grained sandstone and some thin beds of marlstone and siltstone (Cashion and Donnell, 1974).

The basin is a large northwest-trending asymmetric structural downwarp, having very gently dipping limbs on the south and west and more steeply dipping limbs on the north and east. Dips in the Green River Formation range from less than 1° on the south margin to as great as 27° on the north rim. Numerous small subparallel northwest-oriented folds are present, the most prominent being the Piceance Creek dome in the northeastern part of the area.

Several northwest-trending faults, having displacements of less than 15 m (50 ft), have been mapped west of the Piceance Creek dome. Most of the fault zones are coated or filled with calcium carbonate and with minor amounts of solid hydrocarbon. A well-defined system of northwest- and northeast-trending joints is present, and in the west-central part of the area a partial adjustment of streams to this joint system has resulted in trellislike drainage pattern (Donnell, 1961).

Several beds and horizons have been recognized throughout the basin and are useful for correlation purposes (table 1). Some of these beds are altered ash, others are rich oil-shale zones. Two geophysical (resistivity) horizons, the black marker and the orange marker, are extensively used for subsurface correlations. The black marker, a low-resistivity peak, delimits the base of the Mahogany zone (the uppermost rich oil-shale sequence); the orange marker, defined by a unique log configuration, marks the lower limit of the saline minerals or of oil shale of potential economic interest (Donnell and Blair, 1970; Cashion and Donnell, 1972). A third geophysical horizon, the blue marker, lies above the orange marker and represents an abrupt and extreme decrease in the resistivity of the formation over an area of approximately 1,300 km^2 (500 mi^2) at and near the center of the Piceance Creek basin. However, toward the margin of the basin this abrupt break between high and low resistivity climbs progressively higher in the section (J. R. Donnell, written commun., 1976). For the entire basin, the base of the R-2 shale zone (J. R. Donnell, written commun., 1976) should be used as the horizon delineating the break between the Parachute Creek Member and the Garden Gulch Member of the Green River Formation (Cashion and Donnell, 1972).

ECONOMIC CONSIDERATIONS

Marlstone or shale that yield appreciable amounts of oil upon distillation are classed as oil shale. Rich oil shale has a high organic (kerogen) content that imparts a waxy luster and a dark-brown, reddish-brown, or nearly black color to the rock. The high organic content enables the rock to resist erosion better, and rich shale beds weather to ledges, whereas lean and barren marlstone weathers to grooves or slopes (Donnell, 1961).

An oil-shale section, for purposes of this report, is defined as a continuous vertical interval of oil shale that contains a minimum of 60 percent by volume of oil shale which yields greater than 75.7 L/ton (20 gal/ton) of shale oil (fig. 1).

The oil-shale sections were determined from histograms of oil-shale assays that were sampled from continuous core at 0.3-m-(1-ft-) depth intervals obtained from vertical exploratory borings. This limitation, established for an oil-shale section insures that, in general, the shaft will not penetrate thicknesses of "lean" or less than 75.7 L/ton (20 gal/ton) oil-shale sections in layers greater than 30.4 (100 ft) thick. For example, the assay histogram for a particular exploratory core shows that the interval between depths of 304.8 m (1,000 ft)

Table 1.--*Geophysical and stratigraphic horizons, Piceance Creek basin, Rio Blanco County, Colorado*

Horizon	Explanation
A-groove	Oil-lean tuffaceous unit that marks the top of the Mahogany zone.
Mahogany zone	Basal part of upper oil-shale zone composed almost entirely of rich oil shale.
Black marker	Geophysical marker at the base of the Mahogany zone. Related to the B-groove, an oil-lean tuffaceous unit.
Leached zone	Geohydrologic unit in which large amounts of water-soluble minerals (nahcolite and halite) have been removed by ground-water dissolution.
Zone of halite beds	Zone where halite beds of irregular thickness and random distribution are present; thickest bed is 12 m (40 ft).
Blue marker	An abrupt and extreme decrease in the resistivity of the formation.
Orange marker	Geophysical marker generally coinciding with the lower limit of oil shale of potential economic interest.

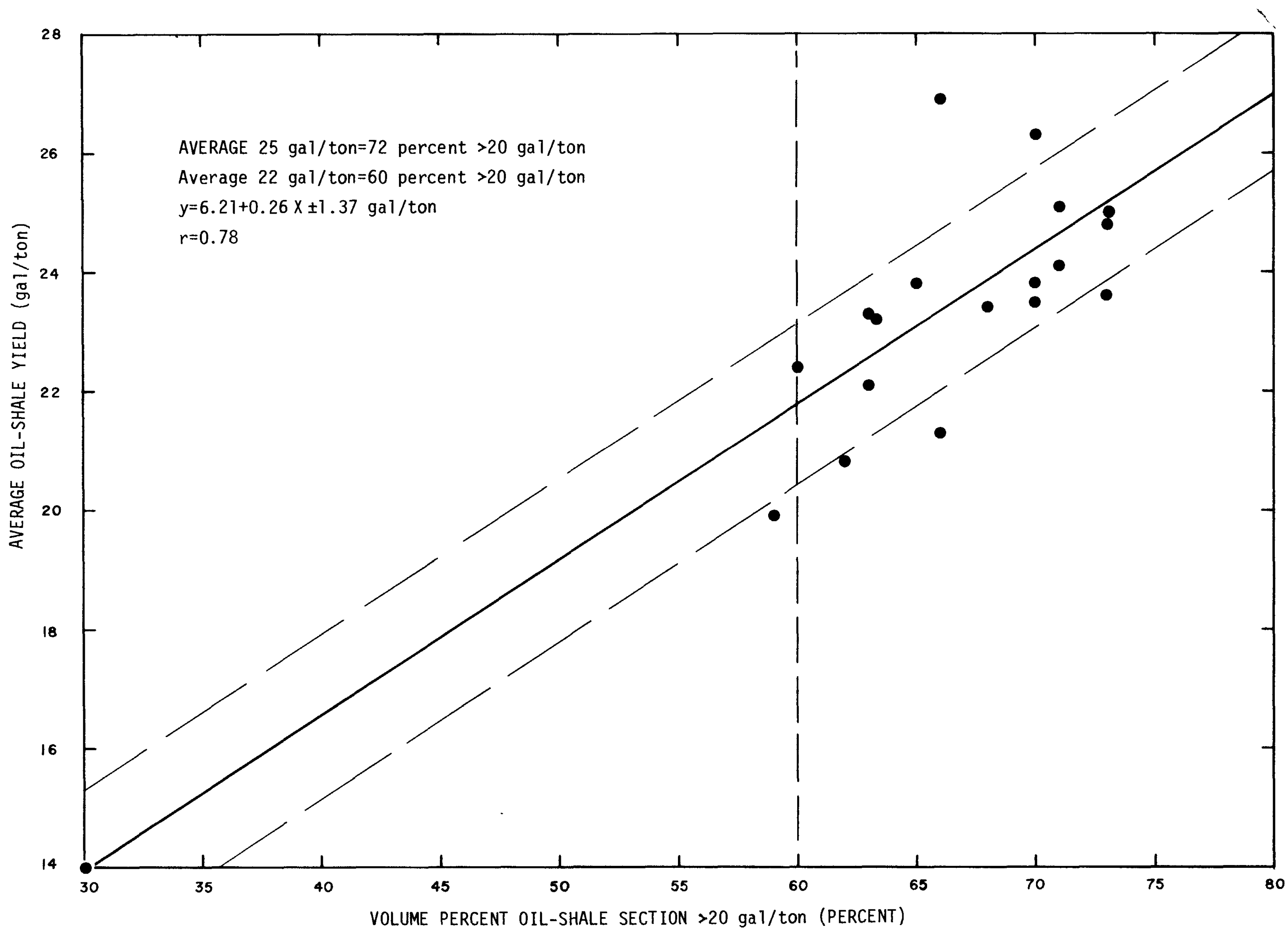

Figure 1.--Relation between percent oil shale in a measured interval and average oil-shale yield.

and 762 m (2,500 ft) contains 320 m (1,050 ft) of oil shale that yields more than 75.7 L/ton (20 gal/ton) of shale oil. This section is, therefore, defined as an oil-shale section of 70 percent, and which yields greater than 75.7 L/ton (20 gal/ton) oil shale. Figure 1 shows the relation between the percentage volume oil-shale sections and their corresponding average shale-oil yields.

The leached zone and saline mineral zones (dawsonite, nahcolite, and halite) were determined from core logs, assays, and reports published by investigators from the USGS and the USBM.

Keighin (1975) estimated that in beds greater than 3.0 m (10 ft) thick and yielding 94.6 L/ton (25 gal/ton), there are 68 billion tonnes (471 billion barrels) of oil in place; of this total, 20 billion tonnes (135 billion barrels) are contained in the Mahogany zone of the Parachute Creek Member. Rich oil-shale zones of potential importance are contained in the Parachute Creek Member; they are the upper Mahogany ledge and the lower zone. In the north-central part of the basin the lower zone contains a thickness of as much as 245 m (800 ft) of oil shale, which averages 100 L/ton (30 gal/short ton) shale oil. The saline minerals in the lower zone dilute the oil shale, resulting in lower oil-yield values. Removal of these saline minerals causes an apparent enrichment of the rock (Trudell and others, 1970).

Donnell and Blair (1970) and Cashion and Donnell (1972) have recognized correlatable oil-shale zones that are differentiated on the basis of their overall high shale-oil content. The Mahogany zone and two other rich oil-shale zones in the lower zone, the R-6 (zone 13 of Dyni, 1974) and R-4 (zone 9 of Dyni, 1974) have been designated as correlatable because of their persistence and their relative lack of contamination by beds of halite and nahcolite. In places in and near the centers of saline deposition, other zones are of equal thickness and richness but the abundance of saline minerals confuse oil-yield values so that correlation of these zones on the basis of oil yield alone is not possible.

Dawsonite (basic carbonate of aluminum and sodium--[$NaAl(OH)_2CO_3$]) and nahcolite (sodium bicarbonate--$NaHCO_3$) deposits of the Piceance Creek basin are distributed throughout a tremendous volume of oil shale. The distribution of these deposits may be controlled by salinity gradients that existed in the lacustrine environment and caused most of the dawsonite and nahcolite to be concentrated in the deeper northern half of the Piceance Creek basin (Hite and Dyni, 1967).

Dawsonite, which contains 35 weight-percent alumina, a potential source of aluminum, occurs as microscopic crystals finely disseminated throughout the oil shale and as thin laminae along bedding planes and in small vugs. The dawsonite shows great vertical and areal distribution in the northern part of the basin. Oil shale containing dawsonite in the center of the basin attains average thicknesses of 215-335 m (700-1,100 ft), the top of the mineralized zone ranges in depth from about 300 to 600 m (1,000 to 2,000 ft) below the surface (Beard and others, 1974).

In an exploratory core near the center of the basin about 92 m (300 ft) of the dawsonite zone averaged 2.3 percent aluminum. Estimates of the alumina contained in dawsonite indicate that about 38 million tons (42 million short tons) are present in 2.6 km^2 (1 mi^2), more than the total bauxite reserves of the United States (Hite and Dyni, 1967).

Nahcolite, a source of sodium bicarbonate, is more abundant and widespread than dawsonite in the basin. Nahcolite occurs in both nonbedded and bedded forms, and scattered throughout much of the saline-rich zone of the Parachute Creek Member are rosette and irregular aggregates of coarse-bladed crystals of brown nahcolite. The lower 186-344 m (610-1,130 ft) of the Parachute Creek Member and the upper part of the Garden Gulch Member consist of low- to high-grade oil shale that contains variable amounts of nonbedded crystalline aggregates of nahcolite and beds of nahcolite and halite (Hite and Dyni, 1967, Dyni, 1974; Beard and others, 1974).

Dyni (1974) estimated that a zone of nahcolite-bearing oil shale at least 30 m (100 ft) thick underlies an area of about 666 km^2 (257 mi^2) and contains at least 29 billion tons (32 billion short tons) of nahcolite. This is the second largest known deposit of sodium carbonate in the world, surpassed only by the Wyoming trona deposits.

DISCUSSION OF POTENTIAL SITES

Four sites (fig. 2; table 2) are presented for consideration as potential shaft locations on the basis of the guidelines discussed earlier. C. W. Keighin (USGS, oral commun., 1976) designated tracts W, X, Y, and Z as potentially suitable mine sites for the USBM in 1974 after considerable evaluation. These are virtually the same tracts we have designated as 1, 2, 3, and 4 (fig. 2). Each site will be described separately. Figures 3-6 show cross sections through potential sites. Table 1 explains the stratigraphic and geophysical horizons used in site descriptions.

Site 1 is located in the north part of the basin and predominantly west of Yellow Creek (fig. 2). Exploratory borings C-34 and C-171 were drilled to define the site. The continuous oil shale, as defined earlier in this report, is not of uniform thickness across the line of section A-A' as one proceeds from west to east (fig. 3). The oil-shale section decreases in thickness from 539.4 m (1,770 ft) at boring C-171 to 320 m (1,050 ft) at boring C-34, the loss occurring in the upper part of the section. This thinning suggests dilution of the marlstone by nonkerogenous materials. A cursory examination of the core logs for the C-34 and C-171 borings shows that C-34 contains thicker lenses of sandstone and siltstone and has higher amounts of core loss and broken core in the leached zone below the A-groove than does C-171. These factors may explain the apparent decrease in shale-oil values in the leached zone in the C-34 boring, or eastern part, of the cross section.

The oil-shale section through the C-171 boring 539.4 m (1,770 ft) thick contains 62 percent by volume of rock that averages 78.7 L/ton (20.8 gal/ton); whereas, the C-34 boring 320 m (1,050 ft) thick contains 60 percent by volume of rock that averages 84.7 L/ton (22.4 gal/ton).

The thickness of the leached zone at C-171 is 167.6 m (550 ft) and at C-34 it is 177.8 m (582 ft). The general zone of halite beds is not present here, although a 3 m (10 ft) zone of halite has been recorded in C-34. No major faults have been mapped at site 1.

Site 2 lies near the center of the basin, predominantly north of Ryan Gulch (fig. 2). Exploratory borings C-13, C-177, and C-7 were used to define the line of section B-B' (fig. 4). The continuous oil-shale section maintains a uniform thickness throughout the area. At C-13 the section is 484.6 m (1,590 ft) thick and contains 72 percent by volume of rock that averages 93.8 L/ton (24.8 gal/ton). At C-177 the section is 499.8 (1,640 ft) thick and contains 63 percent oil shale that averages 88.1 L/ton (23.3 gal/ton), and at C-7 the section contains 479.1 m (1,572 ft) of 63 percent oil shale that averages 83.6 L/ton (22.1 gal/ton).

Table 2.--*Explanation of names of exploratory core holes*

Exploratory core hole	Owner
C-4	Sinclair Fed. 8005
C-6	Sinclair Fed. Strat 1 and 1B
C-7	Pan Am Saterdal-1
C-13	Sinclair Skyline #2
C-34	CCH#1, Colorado Core Hole #1
C-35	CCH#2, Colorado Core Hole #2
C-157	Humble Yellow Creek #1
C-171	CCH#3, Colorado Core Hole #3
C-177	Shell 22X-1
C-192	Superior Strat Test-1
C-197	Shell #A1X-9

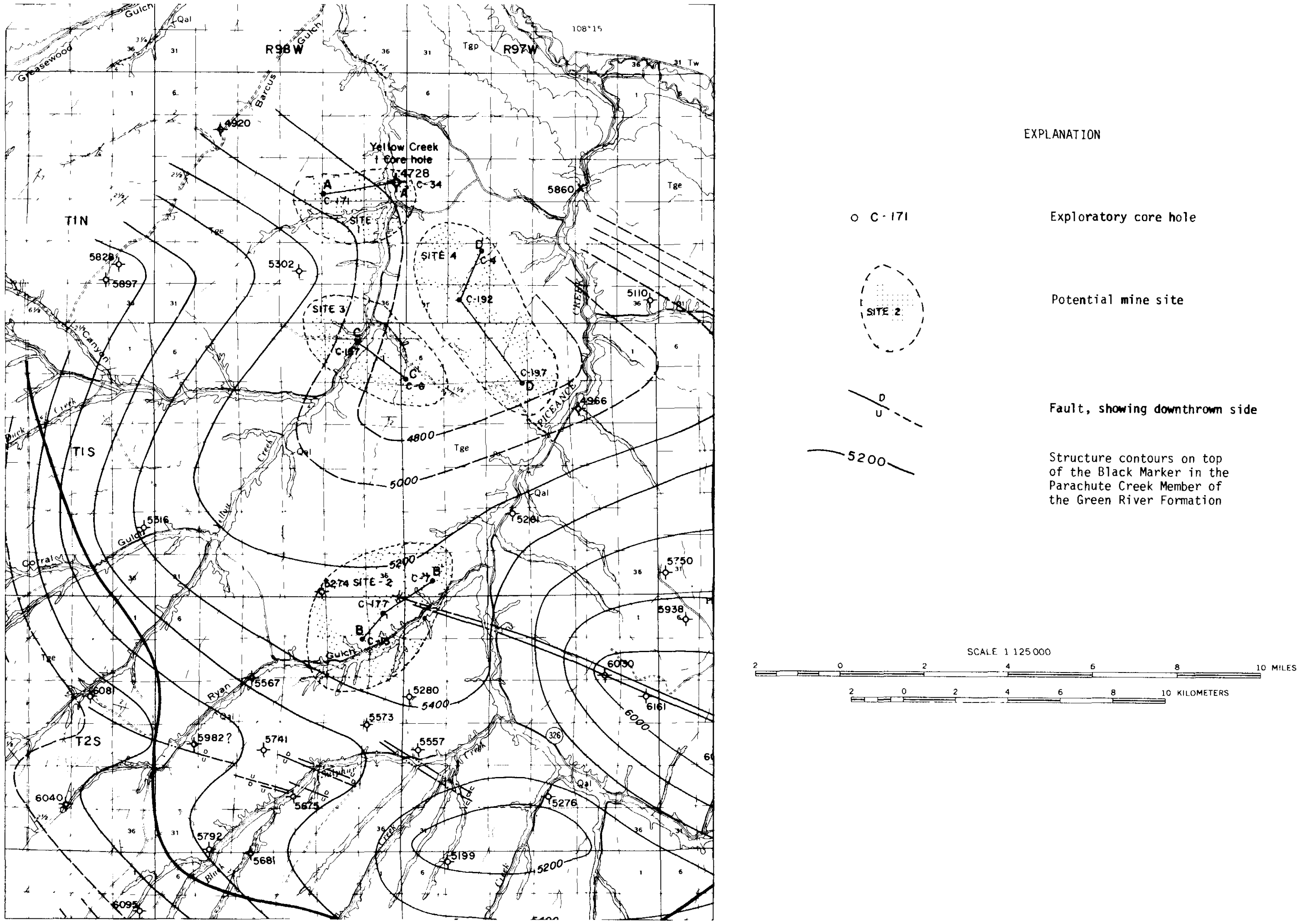

Figure 2.--Index map showing the location of cross sections through U.S. Bureau of Mines potential mine sites 1-4, Piceance Creek Basin, Rio Blanco County, Colorado. (Refer to explanation in table 1.)

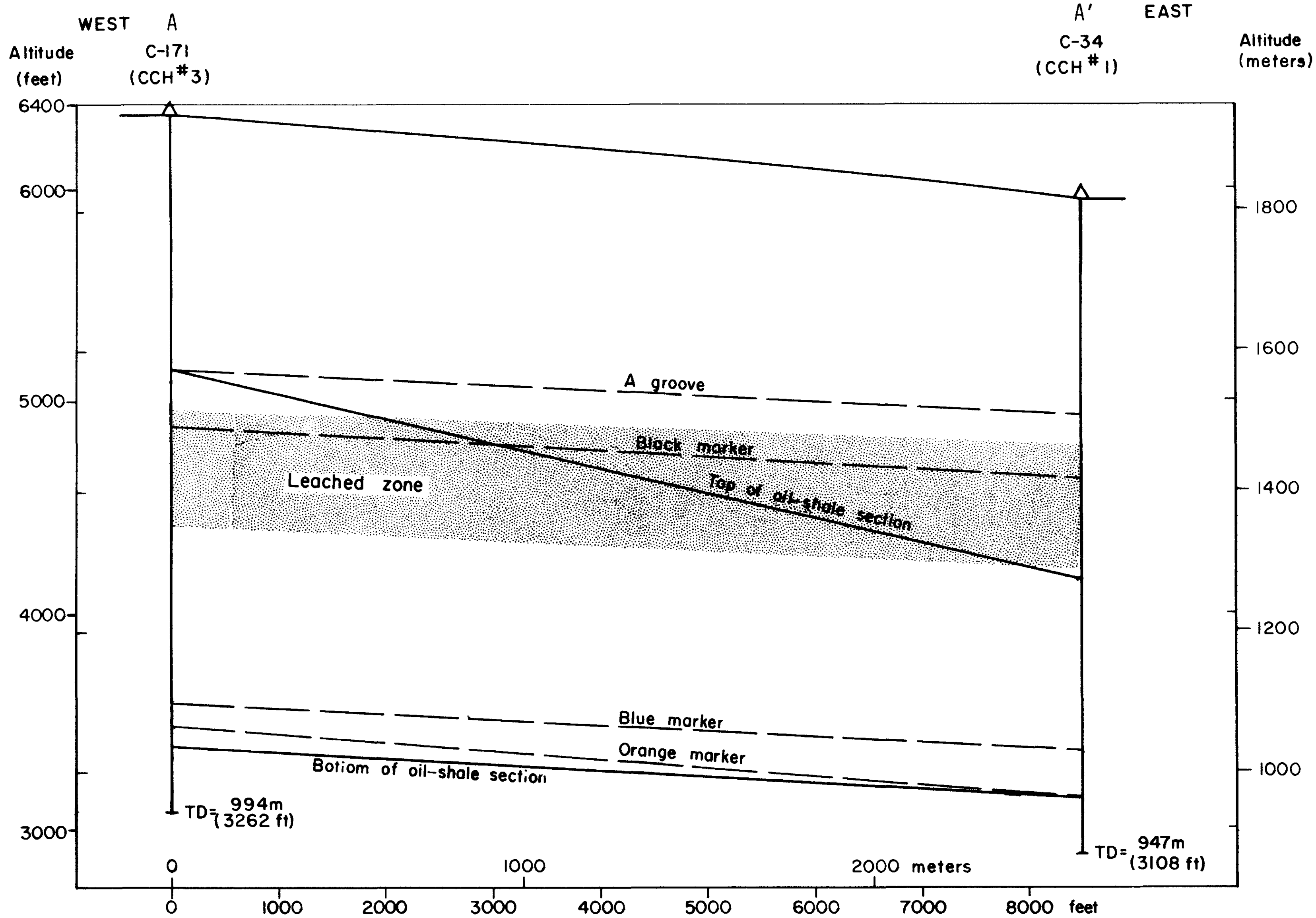

Figure 3.--Cross section A-A' through U.S. Bureau of Mines potential mine site 1.

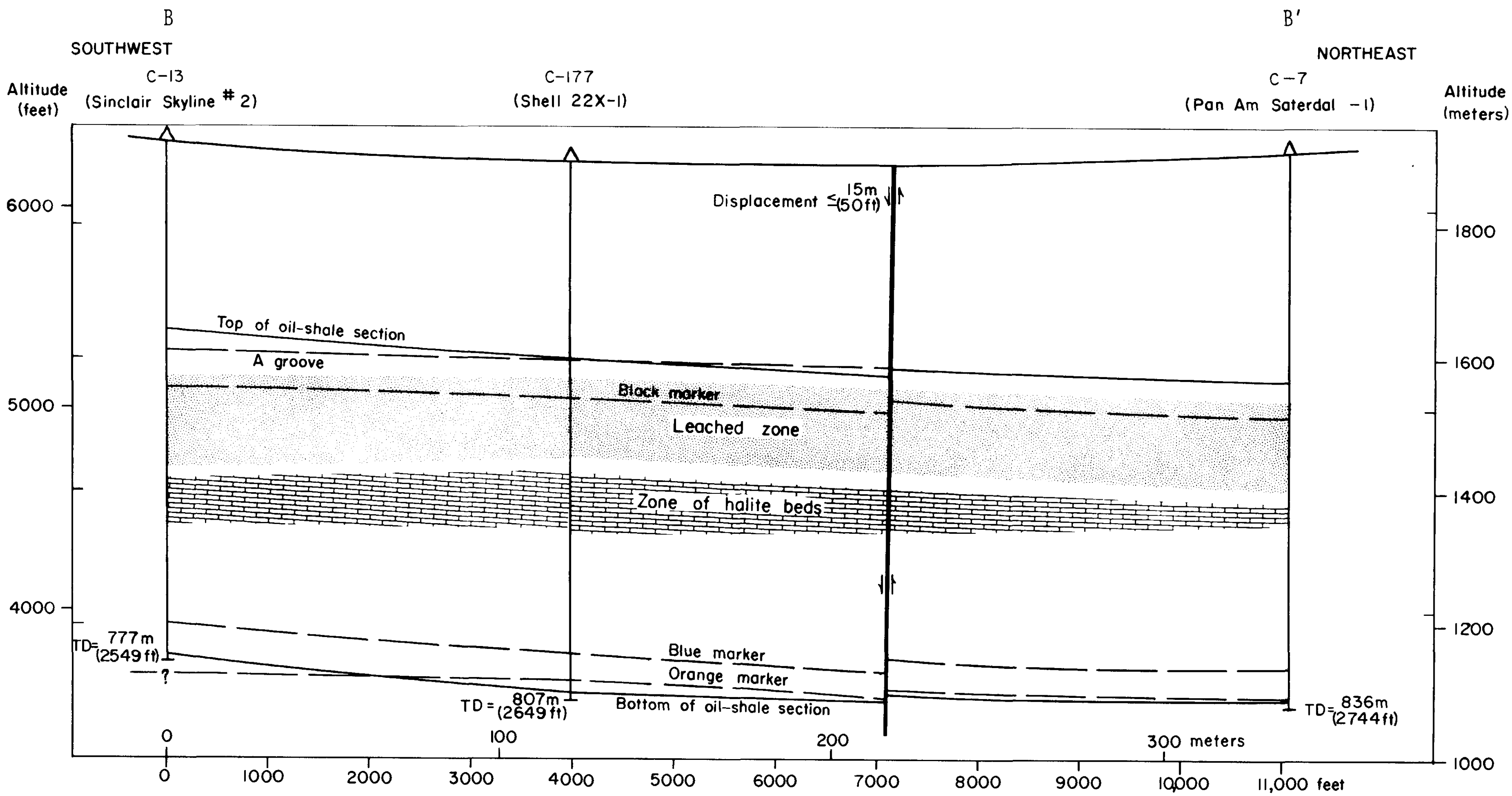

Figure 4.--Cross section B-B' through U.S. Bureau of Mines potential mine site 2.

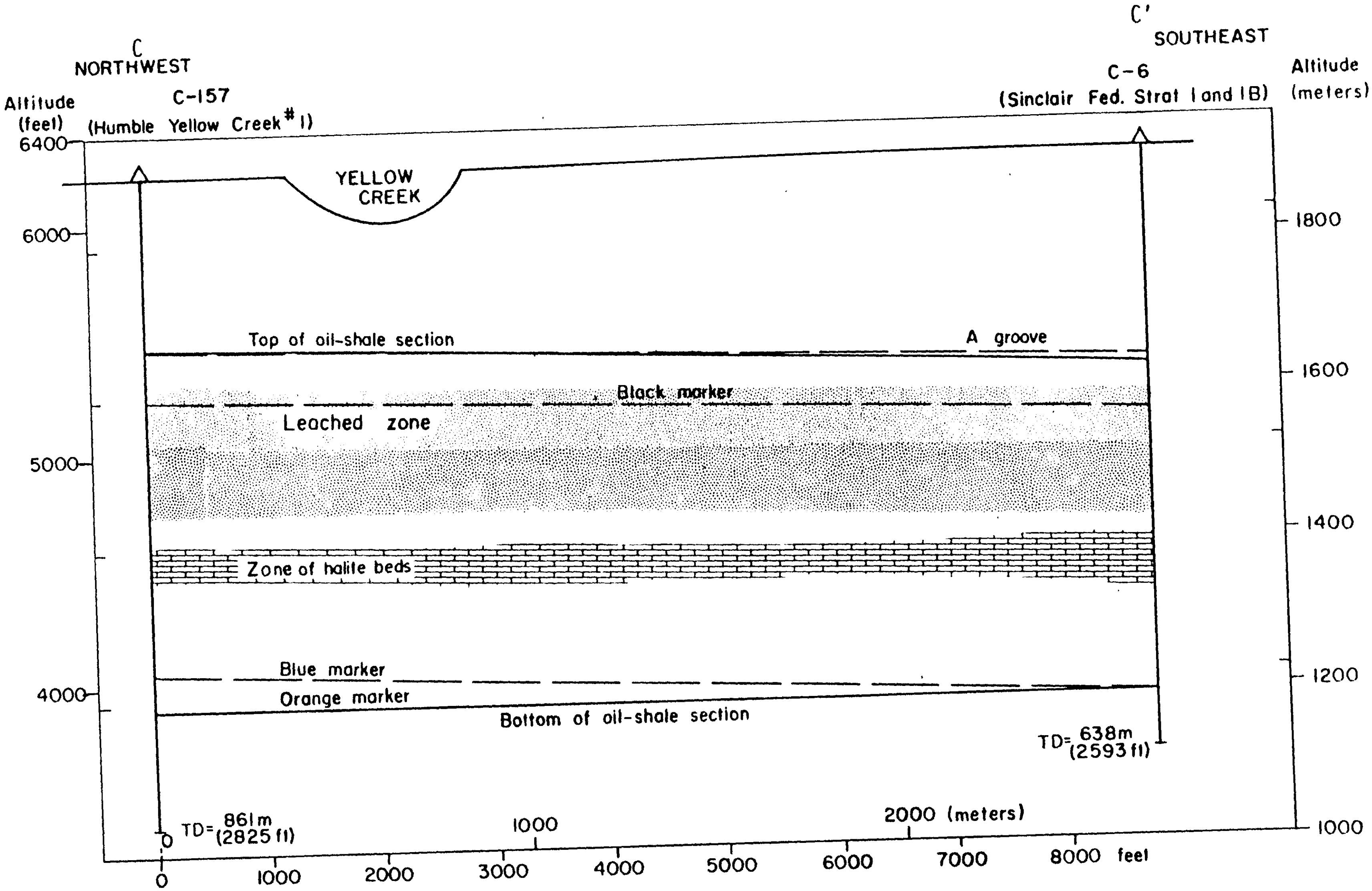

Figure 5.--Cross section C-C' through U.S. Bureau of Mines potential mine site 3.

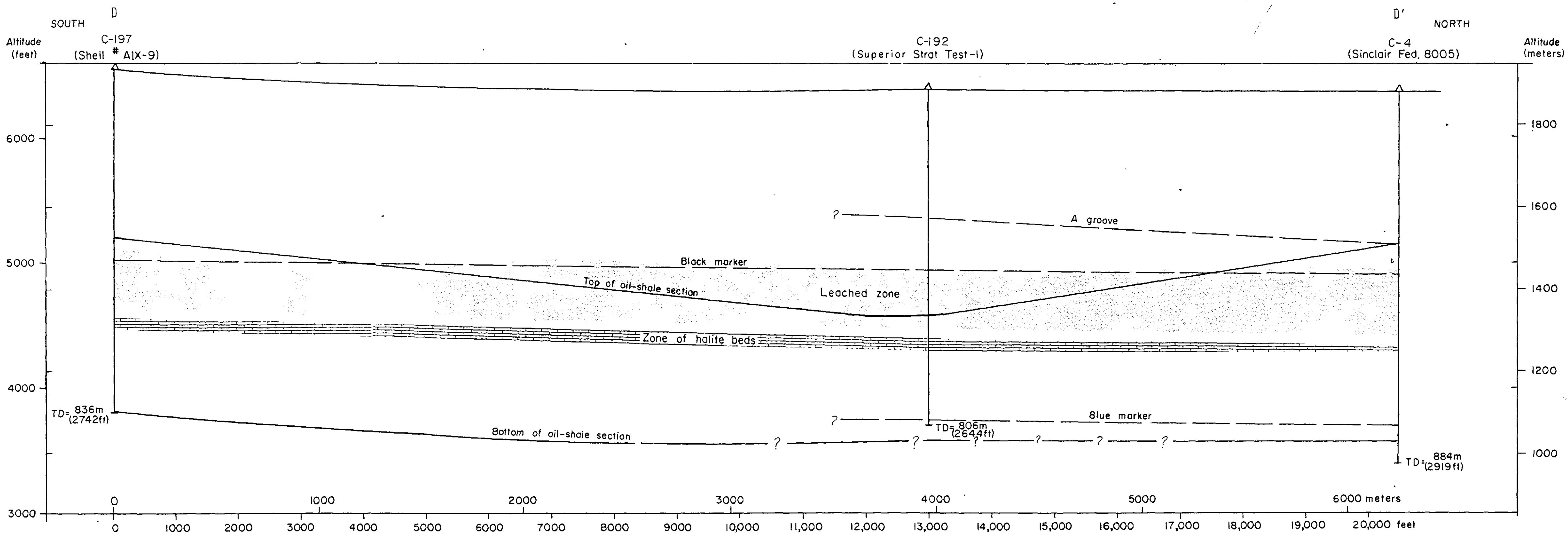

FIGURE 6.--CROSS SECTION D-D' THROUGH U.S. BUREAU OF MINES POTENTIAL MINE SITE 4, PICEANCE CREEK BASIN, RIO BLANCO COUNTY, COLORADO.

The thickness of the leached zone ranges from 121.9 to 137 m (400 to 450 ft) and the thickness of the zone of halite beds ranges from 30.4 to 91.4 m (100 to 300 ft). The maximum thickness of any one halite bed recorded in the C-177 drill hole was 11.2 m (37 ft).

A major fault zone that forms a graben or downdropped structure lies between the C-177 and C-7 drill holes. Fault displacements mapped in the basin are reported to be generally less than 15.2 m (50 ft) (Donnell, 1961).

Site 3 lies in the north part of the basin and straddles Yellow Creek (fig. 2). The site is defined by the C-157 and C-6 borings (fig. 5). The stratigraphic contacts in C-157 are inferred from regional geology; the exact data have been classified as proprietary at this time.

The continuous oil shale maintains uniform thickness along the line of section. At the C-157 drill hole the oil-shale section is 475.4 m (1,560 ft) thick and contains 71 percent by volume of rock that averages 95 L/ton (25.1 gal/ton). The C-6 hole contains 432.8 m (1,420 ft) of 66 percent oil shale that averages 80.6 L/ton (21.3 gal/ton).

The thickness of the leached zone is estimated to be about 76.2 m (250 ft) and the zone of halite beds is about 70.1 m (230 ft). The maximum thickness of any single layer of halite is projected to be less than 15.2 m (50 ft). No faults have been mapped at this location.

Site 4 is located in the northeast part of the basin (fig. 2). The site is defined by the C-4, C-192, and C-197 borings. Data from the C-192 and C-197 holes have been classified as proprietary and cannot be released to the public at this time.

The continuous oil-shale section is not uniform in thickness along the line of section (fig. 6), which is similar to the situation encountered at site 1. This nonuniformity may, as for site 1, be explained by dilution of the oil shale by sandy and silty lenses of sediments and by the leaching of large amounts of saline minerals.

The thickness of the continuous oil-shale section at the C-197 boring is approximately 426 m (1,400 ft) and contains an estimated 60 percent by volume of rock that averages 88.2 L/ton (23.3 gal/ton). The C-192 hole, which did not penetrate the total oil-shale section, contains at least 251 m (824 ft), and for this report is projected to 304.8 m (1,000 ft) of an estimated maximum 71 percent oil shale that averages 81 L/ton (24.1 gal/ton). The C-4 boring contains 484.6 m (1,590 ft) of 65 percent oil shale that averages 90 L/ton (23.8 gal/ton).

The leached zone and zone of halite beds are extrapolated from nearby holes. For site 4 the thickness of the leached zone is estimated to be 152.4 m (500 ft) and the thickness of the zone of halite beds to be 30.4 m (100 ft). No faults have been mapped in the area.

ENGINEERING GEOLOGY

Serious construction and support problems are anticipated in the sinking of a deep shaft in the Piceance Creek basin. The two major concerns are incompetent rock and large inflow of saline ground water. The worst mining conditions will be found in the leached zone, a geohydrologic unit in which large amounts of the water-soluble minerals nahcolite and halite have been removed by ground-water dissolution. The removal of the saline minerals has produced a highly porous and permeable, vuggy, fractured and brecciated, low-strength rock. In addition, this porous and permeable zone is an aquifer that contains large amounts of highly saline ground water which must be removed and disposed of during mining operations.

Support problems will include stabilizing and hardening the rock from which a certain amount of ground water has been removed, thereby leaving voids that were formerly filled with water. Under the increased stress concentrations created by the mined opening, there is a strong possibility that the dewatered oil shale will collapse around the shaft. Another engineering problem will be to prevent water inflow into the shaft and to take into account any hydraulic head acting on the shaft walls at depths exceeding 304.8 m (1,000 ft).

Figure 7 is an engineering-properties log for borings C-34, C-171, and C-35. The black marker is used as the datum on the log and core index is plotted against hole depth. The core index is a numerical value ranging from 0 to 100 that quantifies the degree of fracturing of the rock, increasing core index values signify increasing numbers of fractures. The core index is a measure of core loss, broken core, and fractures observed in the core and which are logged on an ordered basis. The core index has been used extensively in exploratory, tunnelling, and shaft projects in which the USGS has been involved, and considerable experience has been gained in applying the concept to practical engineering programs. In general, a core-index value greater than 50 indicates incompetent rock.

A general core-index pattern can be observed for the three borings (fig. 7). Above the A-groove and the leached zone there is an interval of moderately high core-index values. This interval passes through brittle beds of sandstone and siltstone and represents fractured rocks. A second interval, between the A-groove and the black marker, shows a thick zone of high core-index values in the C-34 and C-171 borings and a much thinner zone in the C-35 boring. This latter interval represents the leached zone and is characterized by high core loss and strongly broken core. Borings C-34 and C-171 are located near the center of the basin and near the center of the saline deposition; they apparently have had a larger volume of salines available for dissolution. Boring C-35, which is not in a basin, is about 3.6 km (8.5 mi) southwest of C-34 and C-171 and apparently has been less affected by dissolution and is, therefore, less brecciated.

Table 3 lists physical property values from core taken from the C-171 boring. Core samples were gathered at various depths and represent several rock types and environments. The unleached oil shale can be classified as a medium-strength low-elastic-modulus-ratio rock; that is, a rock having a uniaxial compressive strength that ranges from 55.2 MPa to 110.4 MPa (8,000 to 16,000 lb/in^2) and a modulus ratio of less than 200.

$$\frac{\text{Young's modulus}}{\text{Compressive strength}} < 200$$

(See Deere and Miller, 1966.)

CONCLUSIONS

The relative suitability of the four potential oil-shale experimental shaft and mine sites in the Piceance Creek basin has been considered on the basis of all available geologic, hydrologic, and engineering data. The hydrology is discussed in detail in the hydrology section of this report by J. B. Weeks, and G. H. Leavesley (USGS).

We rank the suitability of the four potential sites as follows, with rank 1 being the most favorable:

Location	Rank
Site 2	1
Site 3	2
Site 1	3
Site 4	4

Site 2 is considered the most favorable. The oil-shale section thickness is uniform and the quantity and salinity of ground water are less than the other three sites (J. B. Weeks,

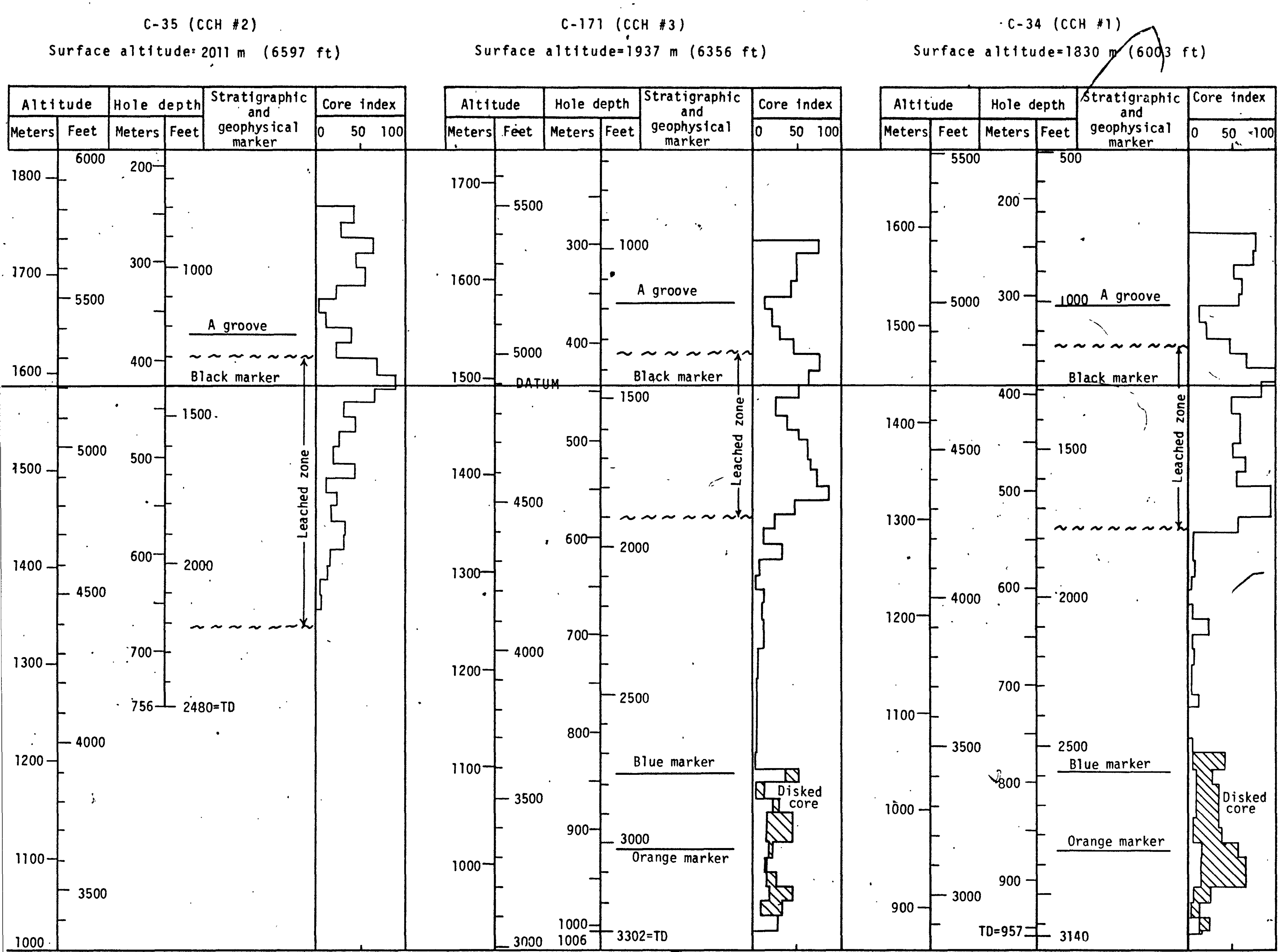

Figure 7.--Graph showing engineering-properties log for drill holes C-35, C-171, and C-34.

Table 3.--*Physical properties, C-171 (CCH #3) core hole, Rio Blanco County, Colorado*

[Location: SW 1/4, SW 1/4, SW 1/4 sec. 14, T. 1 N., R. 98 W.; altitude: 1,947 m (6,356 ft). Analysts: Philip Powers and A. F. Chleborad]

Hole depth (feet)	Rock type	Saturated bulk density (calculated total g/cm³)	Dry bulk density (mercury displacement g/cm³)	Grain density (powdered grain in kerosene g/cm³)	Porosity (calculated total percent)	Shore hardness (shore units)	Dynamic properties: Compressional velocity (ft/s)	Dynamic properties: Shear velocity (ft/s)	Dynamic properties: Poisson's ratio	Dynamic properties: Young's modulus (10^6 lb/in²)	Dynamic properties: Shear modulus (10^6 lb/in²)	Dynamic properties: Bulk modulus (10^6 lb/in²)	Static properties: Poisson's ratio	Static properties: Secant Young's modulus (10^6 lb/in²)	Static properties: Shear modulus (10^6 lb/in²)	Static properties: Bulk modulus (10^6 lb/in²)	Static properties: Unconfined compressive strength
1,356	Oil shale	2.27	2.27	2.28	0.44	49	12,796	7,481	0.24	4.23	1.71	2.71	0.22	1.24	0.74	0.51	18,000
1,456	Leached oil shale	2.29	2.21	2.40	7.92	44	10,434	5,807	0.27	2.54	1.00	1.84	0.24	1.76	1.13	0.71	14,000
1,652	Leached oil shale	2.32	2.14	2.60	17.69	35	--	--	--	--	--	--	--	--	--	--	--
1,918	Leached oil shale	2.40	2.34	2.48	5.65	51	14,075	7,907	0.27	5.00	1.97	3.62	--	--	--	--	--
1,992	Oil shale	2.14	2.13	2.16	1.39	38	9,581	5,873	0.20	2.37	0.99	1.32	0.25	1.14	0.76	0.46	13,000
2,108	Oil shale	2.02	2.01	2.04	1.47	43	8,235	4,692	0.26	1.50	0.60	1.04	0.085	0.31	0.12	0.14	13,800
2,296	Oil shale with nahcolite-filled vugs	2.12	1.94	2.37	17.72	24	10,434	5,020	0.35	1.78	0.66	1.98	0.14	0.79	0.36	0.35	3,200
2,650	Oil shale	2.10	2.10	2.12	1.42	50	10,270	5,805	0.26	2.40	0.95	1.67	0.23	0.50	0.31	0.20	11,000
3,005	Claystone	2.53	2.52	2.54	0.79	47	15,257	8,498	0.28	6.27	2.45	4.75	0.13	3.93	1.77	1.74	16,000
3,065	Silty claystone	2.29	2.25	2.35	4.26	37	11,549	6,070	0.31	2.92	1.12	2.56	--	--	--	--	--
3,118	Silty claystone	2.31	2.27	2.37	4.22	24	13,879	8,203	0.23	5.06	2.06	3.12	--	--	--	--	--
3,165	Dolomitic siltstone	2.42	2.26	2.70	16.30	36	11,812	7,054	0.22	3.69	1.31	2.20	0.16	1.35	0.66	0.58	6,900
3,178	Dolomite	2.54	2.44	2.72	10.29	31	13,386	8,203	0.20	5.31	2.21	2.95	--	--	--	--	--
3,253	Siltstone	2.54	2.48	2.65	6.42	37	--	--	--	--	--	--	--	--	--	--	--
Selected average values for all samples																	
					6.86		11,809	6,718		3.59	1.42	2.48		1.38	0.73	0.59	11,988

oral commun., 1975). The site is near a major west-northwest-trending fault zone, and, therefore, it is recommended that aerial photographs to be studied for the presence of faults or lineations before final site selection is made. The character of the leached zone is anticipated to be similar to that at the other three sites.

Site 3 is ranked second. The oil-shale-section thickness is uniform but the quantity and salinity of ground water are greater than at site 2 (J. B. Weeks, oral commun., 1975). There are no faults mapped in the vicinity and the character of the leached zones will not differ from those other three sites.

Site 1 is ranked third. The thickness of the oil-shale section is not constant, decreasing toward the east. The nonuniformity of thickness makes predictability of shale-oil yields less certain than at sites 2 and 3. The quantity and salinity of ground water are greater than site 2 but similar to sites 3 and 4 (J. B. Weeks, oral commun., 1975). There are no faults mapped in the vicinity and the character of the leached zone is similar to that at the other three sites.

Site 4 is ranked fourth. The thickness of the oil-shale section is constant and the salinity and quantity of ground water are greater than site 2 but similar to sites 3 and 1. There are no faults mapped in the area. The character of the leached zone is expected to be similar to that at the other three sites.

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HYDROLOGIC EVALUATION OF FOUR PROTOTYPE MINE SITES IN THE PICEANCE CREEK BASIN, COLORADO

By

John B. Weeks and George H. Leavesley

INTRODUCTION

The previous section of this report describes the location, geology, and mineral resources of four sites in the Piceance Creek Basin, Colorado. These sites meet the geologic and resource requirements set forth by the USBM (U.S. Bureau of Mines) for oil-shale-mining research and development. This section describes the water resources and hydrologic characteristics of the four sites, including estimates of the quantity and quality of ground water which would be produced from a mine shaft at each of the sites.

The hydrology of the Piceance Creek Basin has been described by Weeks and others (1974). Hydrologic data collected in the basin were reported in two basic-data reports by Ficke, Weeks, and Welder (1974) and Weeks and Welder (1974). In addition, Wymore (1974) estimated the average annual water budget for the basin. The following information used to describe the hydrology of the four proposed sites was obtained from the above reports.

SURFACE WATER

General Description

The four sites shown on figure 8 have similar topography, vegetation, and climate. The altitudes of the sites and adjacent areas range from 1,830 to 2,070 m (6,000-6,800 ft). The predominant vegetation types at each site are sagebrush and piñon-juniper. The climate at all sites is semiarid. Average annual precipitation ranges from about 300 mm (12 in.) at 1,830 m (6,000 ft) to about 380 mm (15 in.) at 2,070 m (6,800 ft). Precipitation generally occurs as snow from November to March and as rain during the remainder of the year. Precipitation volume is evenly distributed throughout the year. Annual potential evapotranspiration for a horizontal surface ranges from about 1,170 mm (46 in.) at 1,830 m (6,000 ft) to about 1,090 mm (43 in.) at 2,070 m (6,800 ft).

Each site is bounded by and contains only intermittent streams. Runoff occurs only from rapid snowmelt or high-intensity thunderstorms. Most of the annual precipitation received is used to satisfy soil-water storage deficiencies and is subsequently lost through evapotranspiration. Ground-water recharge on these sites may occur during years with above-normal winter precipitation.

Runoff rates and volumes are dependent on individual storm and basin characteristics. Infiltration rates for conditions similar to those on the selected sites were measured by J. R. Meiman (written commun., 1974). The results indicate that infiltration rates average from 25 to 51 mm/hr (1-2 in./hr) for a simulated storm intensity of about 89 mm/hr (3.5 in./hr). For the Piceance Creek Basin, Hershfield (1961) estimated the 100-year, 1-hour point rainfall to be 37 mm (1.45 in.) and the probable maximum 6-hour precipitation for a 25.9 km^2 (10 mi^2) area to be about 250 mm (10 in.). Using 25 mm/hr (1 in./hr) infiltration rate, total runoff

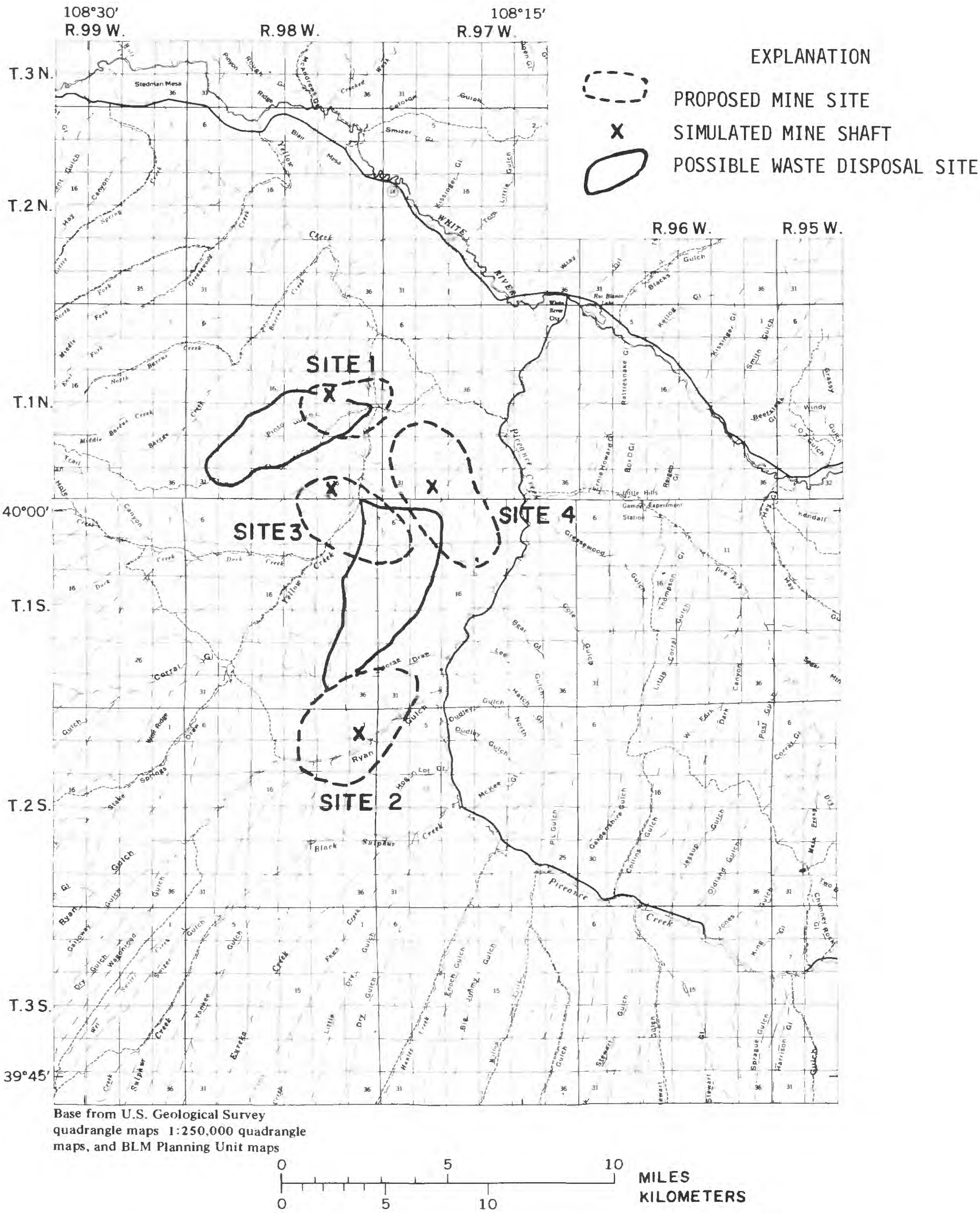

Figure 8.--Location of proposed mine sites, simulated mine shafts, and possible waste disposal sites.

for the 100-year, 1-hour storm could be 18 mm (0.7 in.) from the drainages within and adjacent to the proposed sites. The U.S. Soil Conservation Service (1971) estimates that runoff from the probable maximum 6-hour storm could be about 165 mm (6.5 in.) for these same basins. Flood problems could be avoided at the four sites by keeping development activities from 9.1 to 15.2 m (30-50 ft) above existing flood plains.

Waste Disposal

Control of runoff from mining and waste-disposal sites and disposal of waste water from the mine are of importance primarily from a water-quality standpoint. Erosion, sedimentation, and chemical-quality degradation are all surface-water problems to be anticipated with the mining operation. Erosion and sedimentation can be minimized with proper control structures and development practices. Chemical-quality degradation of surface waters can be minimized by treatment to improve the quality of discharge to surface streams or by discharging to storage ponds where the water would be evaporated.

For a plant producing oil at a rate of 8,000 m^3/d (50,000 bbl/d), an estimated 63,500 t/d (70,000 t/d) of oil shale containing recoverable oil averaging 125 L/ton (30 gal/t) would be required. Retort wastes from an operation this size would be about 55,300 t/d (61,000 t/d). Compacted to a density of 1,440 kg/m^3 (90 lb/ft^3), this volume of waste would require approximately 14.2 hm^3 (11,500 acre-ft) of storage annually or about 425 hm^3 (345,000 acre-ft) for a mine with a life of 30 years. Depending upon the density of the oil shale, the volume of the waste would be 25-50 percent greater than the volume in place. The size of the required disposal storage and its potential for water-quality degradation necessitates consideration of spent-shale disposal sites in the selection of the mining site.

Spent shale contains large quantities of soluble salts which can be removed by water moving across or percolating through disposal piles. The U.S. Environmental Protection Agency (1971) reported that a leaching study on spent-oil-shale residues showed a definite potential for high concentrations of sodium, calcium, magnesium, and sulfate ions. Initial leachate samples had sulfate-ion concentrations of 90,000 mg/L (milligrams per liter) and sodium-ion concentrations of 35,000 mg/L. Succeeding leachate samples showed a marked decrease in the concentrations of major ions. However, predicted steady-state concentrations for the following ions were: sodium, 86 mg/L; calcium, 64 mg/L; magnesium, 118 mg/L; sulfate, 740 mg/L; and chloride, 11 mg/L.

The physical and hydrologic properties of disposal piles are a function of the oil-shale retorting process, the degree of vegetative cover established on the piles, and the degree of pile compaction (Striffler and others, 1974). With a policy of nondegradation of surface waters, all storm runoff and seepage from such piles would have to be contained. Most of the drainage areas acceptable for storage have deep alluvial fills near their mouths. Impoundment of water in these drainage areas without seepage to a stream channel would be difficult. The intermittent nature of the streams in the vicinity of the four sites would probably permit the consumption of small discharges by phreatophytic vegetation. However, large salt deposits along stream channels would result. The salt deposits would be available for movement downstream during runoff periods and would ultimately reach the White River. Consequently, the availability of spent-shale disposal sites, where runoff can be contained, is an important factor in the selection of a prototype mine site.

There are two drainage areas that are close to the selected sites and have adequate storage capacity for a long-term oil-shale operation; they are Pinto Gulch and an unnamed tributary to Yellow Creek (fig. 8) whose mouth is located in site 3. Pinto Gulch has an area of about 16.6 km^2 (6.4 mi^2) and the unnamed tributary has an area of about 25.6 km^2 (9.9 mi^2). Depending on storage techniques and compaction densities used, Pinto Gulch could hold the major part of disposal waste from a 30-year, 8,000-m^3/d (50,000-bbl/d), retort operation. The unnamed tributary to Yellow Creek could possibly hold all of this waste. Pinto Gulch has a larger ratio of storage volume to pile surface area but the unnamed tributary has a larger total storage volume available. The minimization of pile surface area means fewer acres requiring revegetation. The mouths of Pinto Gulch and the unnamed tributary are on land owned by the State of Colorado. Sodium mineral leases have been let by the U.S. Bureau of Land Management on land within the drainage of the unnamed tributary to Yellow Creek.

GROUND WATER

General Description

The ground-water system in the Piceance Creek Basin consists of two principal aquifers that are separated by the Mahogany zone in the Parachute Creek Member of the Green River Formation as shown on figure 9. The Mahogany zone is less permeable than the aquifers it separates. Recharge to the aquifers mainly occurs from snowmelt above an altitude of 2,130 m (7,000 ft) along the basin margins. The recharge infiltrates to the upper aquifer and flows toward the north-central part of the basin. In the recharge area, the hydraulic head in the upper aquifer is higher than that in the lower aquifer and water moves downward, through the Mahogany zone, to the lower aquifer. In the north-central part of the basin and in the major stream valleys, the heads in the aquifers are reversed and water moves upward from the lower aquifer through the Mahogany zone into the upper aquifer. Water from the aquifers is eventually discharged as evapotranspiration and baseflow in the streams.

At the time of deposition, part of the lower aquifer contained highly soluble minerals as much as 20 percent by volume. Percolating water is actively leaching these minerals and this part of the lower aquifer is frequently referred to as the leached zone. The Mahogany zone impedes the movement of water between the aquifers and large chemical differences have developed. Water in the upper aquifer generally has less than 2,000 mg/L dissolved solids except where discharge from the lower aquifer affects the water quality of the upper aquifer. The concentration of dissolved solids in the lower aquifer exceeds 30,000 mg/L in the northern part of the basin.

Dewatering

A digital model of the ground-water system (Weeks and others, 1974) was used to estimate the discharge that would be produced during the construction of a vertical mine shaft, 6 m (20 ft) in diameter, at each of the four proposed sites. The mine shaft will penetrate the upper and lower aquifers and terminate in the high-resistivity zone (fig. 9). The model analysis assumed that the shaft was deepened at the rate of 6 m (20 ft) per day and that ground water was pumped from the shaft at a rate sufficient to dewater the shaft.

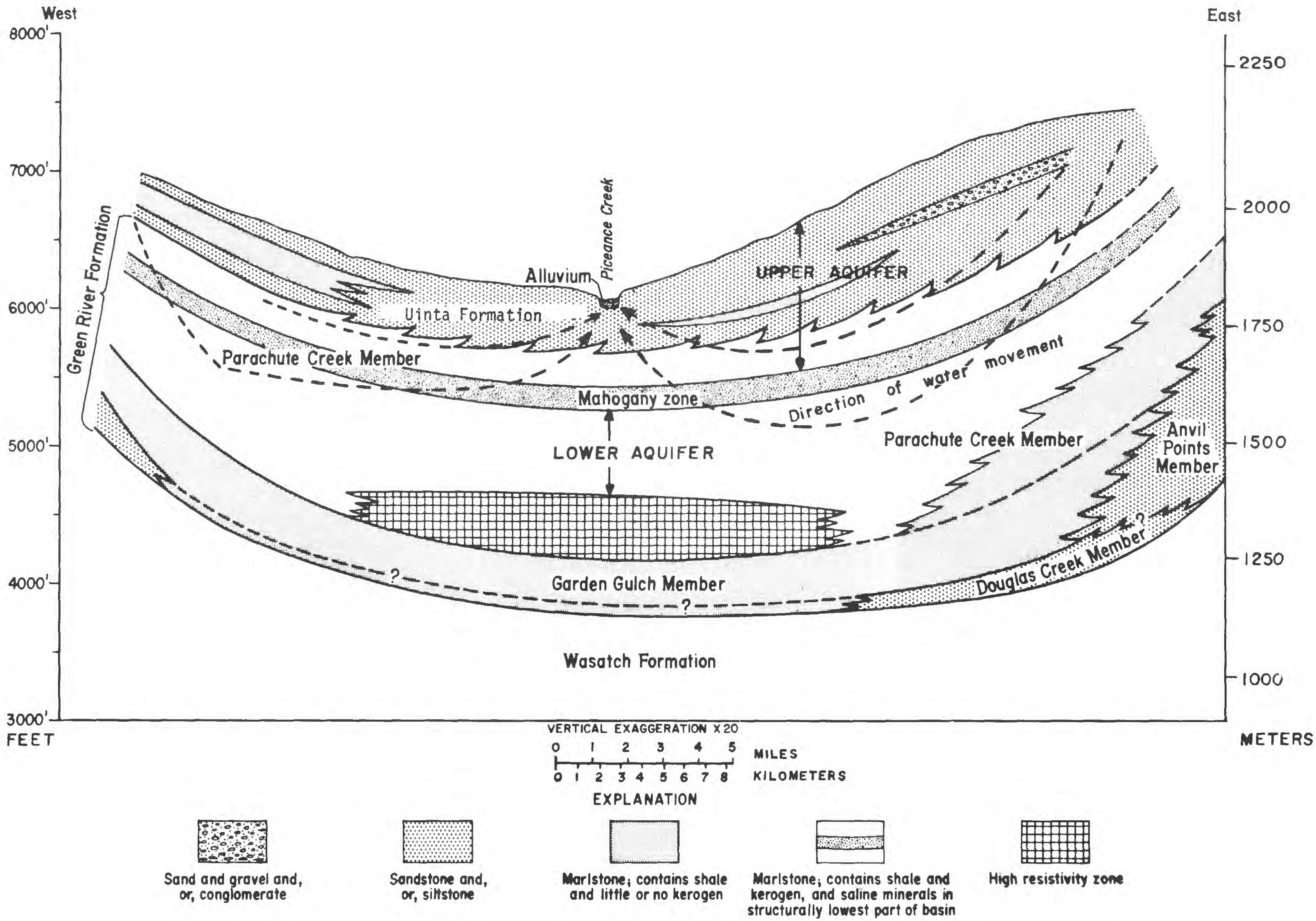

Figure 9.--Diagrammatic geohydrologic section through the Piceance Creek Basin.

The mine shaft at each site was simulated by a single node in each layer of the digital model. The hydraulic head at the node representing the mine shaft in the upper aquifer was made to decline at the rate of 6 m (20 ft) per day until the head declined to the top of the Mahogany zone, after which a constant head was maintained in the upper aquifer equal to the altitude of the top of the Mahogany zone. When the simulated mine shaft penetrated the bottom of the Mahogany zone, the head in the lower aquifer was drawn down to the bottom of the Mahogany zone and made to decline at the rate of 6 m (20 ft) per day until the shaft reached the high-resistivity zone. The flow rate into the shaft was calculated by applying Darcy's law between the nodes representing the mine shaft and adjacent nodes in the model. No attempt was made to simulate grouting or other methods of preventing or retarding ground-water inflow to the shaft during construction. Consequently, the flow rates computed by the model represent conditions of unretarded flow into the shaft.

The node spacing used in the model represents 1.6 km (1 mi) between nodes. This results in larger flow rates to the mine shaft than would result using a smaller grid spacing. Thus, the magnitude of the computed discharge is larger than that expected for a shaft 6 m (20 ft) in diameter. However, the relative differences in discharge between the proposed sites are not affected by the grid spacing used in the model.

The reduction in discharge that would result for a shaft 6 m (20 ft) in diameter can be estimated for steady-state flow conditions. It has been shown (P. C. Trescott, oral commun., 1975) that the drawdown at a node in a digital model with uniform grid spacing, w, used to simulate a discharge well in a confined aquifer, is equal to the theoretical drawdown at a radial distance w/4.81 from the well. Therefore, the discharge computed by the digital model is the result of 6 m (20 ft) of drawdown per day at a distance of 5,280/4.81=335 m (1,098 ft) from the center of the mine shaft. For steady-state conditions, the discharge, Q, is given by the following equation in consistent units:

$$Q = \frac{2\pi T(h_2-h_1)}{\ln(r_2/r_1)},$$

where T is the transmissivity of the aquifer and h_1 and h_2 are the hydraulic heads measured at the distances r_1 and r_2 from the discharge well. Thus, the discharge for a shaft with a 3-m (10-ft) radius, with the same drawdown as that simulated in the digital model, is related to the discharge computed by the model, Qm, by the following equation:

$$Q = \frac{\ln(r_o/r_m)}{\ln(r_o/r)} Qm,$$

where r_o is the radius of the cone of depression, r_m is 335 m (1,098 ft), and r is 3 m (10 ft), the radius of the mine shaft. Assuming r_o is of the order of 16 km (10 mi) or 16,093 m (52,800 ft), then

$$Q = \frac{\ln(52{,}800/1{,}098)}{\ln(52{,}800/10)} Qm,$$

$$Q=0.45\ Qm.$$

Although the discharge computed by the model is for transient conditions, it can reasonably be assumed that the discharge computed by the model may be about twice that which would result from the construction of a mine shaft 6 m (20 ft) in diameter.

HYDROLOGIC CHARACTERISTICS

Site 1

Site 1 is 16 km (10 mi) upstream from the confluence of Yellow Creek and the White River (fig. 8). The drainage area of Yellow Creek above site 1 is 448 km^2 (173 mi^2). All streams in the vicinity of site 1 are intermittent. No surface water would be available at the site except during periods of snowmelt runoff. Discharge of waste water from the site could be contained in one of the several small drainage areas on the site that is tributary to Yellow Creek. The principal advantages of site 1 are its proximity to Pinto Gulch and its location in the Yellow Creek drainage basin.

The location of the simulated mine shaft at site 1 is shown on figure 8. Construction of the shaft will penetrate about 550 m (1,800 ft) of water-bearing rocks before reaching the high-resistivity zone. The upper aquifer is 305 m (1,000 ft) thick and has a transmissivity of about 13 m^2/d (140 ft^2/d). The lower aquifer is 185 m (600 ft) thick and has a transmissivity of about 62 m^2/d (670 ft^2/d). The storage coefficient of the upper aquifer is estimated to be 10^{-3} and that of the lower aquifer is estimated to be 10^{-4} at each of the four sites. Under dewatering conditions, the storage coefficient was assumed to be 10^{-1} in the upper aquifer at each of the four sites.

The computed discharge for the mine shaft at site 1 is shown on figure 10. At a depth of 550 m (1,800 ft), the discharge from the shaft is about 1.1 m^3/s (40 ft^3/s). The area of the cone of depression after 90 days of dewatering is superimposed on the map of dissolved-solids concentration for each aquifer in figures 11 and 12. The concentration of dissolved solids in the water produced during the construction of the shaft is estimated to be 1,500-2,000 mg/L from the upper aquifer and about 20,000 mg/L from the lower aquifer.

Site 2

The area of site 2 is tributary to Ryan Gulch, 3.2 km (2 mi) above its confluence with Piceance Creek (fig. 8). The drainage area of Ryan Gulch above the site is about 106 km^2 (41 mi^2). All streams near the site are intermittent except Piceance Creek. Waste water produced at the site could be contained in one of several tributaries to Ryan Gulch; however, higher control structures would be required than at other sites because of steep, narrow drainages. Spent shale could be disposed of in the drainage area of the unnamed tributary to Yellow Creek which lies directly to the north (fig. 8).

The location of the simulated mine shaft at site 2 is shown on figure 8. Construction of the shaft will penetrate 460 m (1,500 ft) of saturated section before reaching the high-resistivity zone at a depth of about 535 m (1,750 ft). The upper aquifer is 215 m (700 ft) thick and has a transmissivity of 13 m^2/d (140 ft^2/d). The lower aquifer is 170 m (550 ft) thick and has a transmissivity of 37 m^2/d (400 ft^2/d). The storage coefficients are estimated to be the same as at site 1.

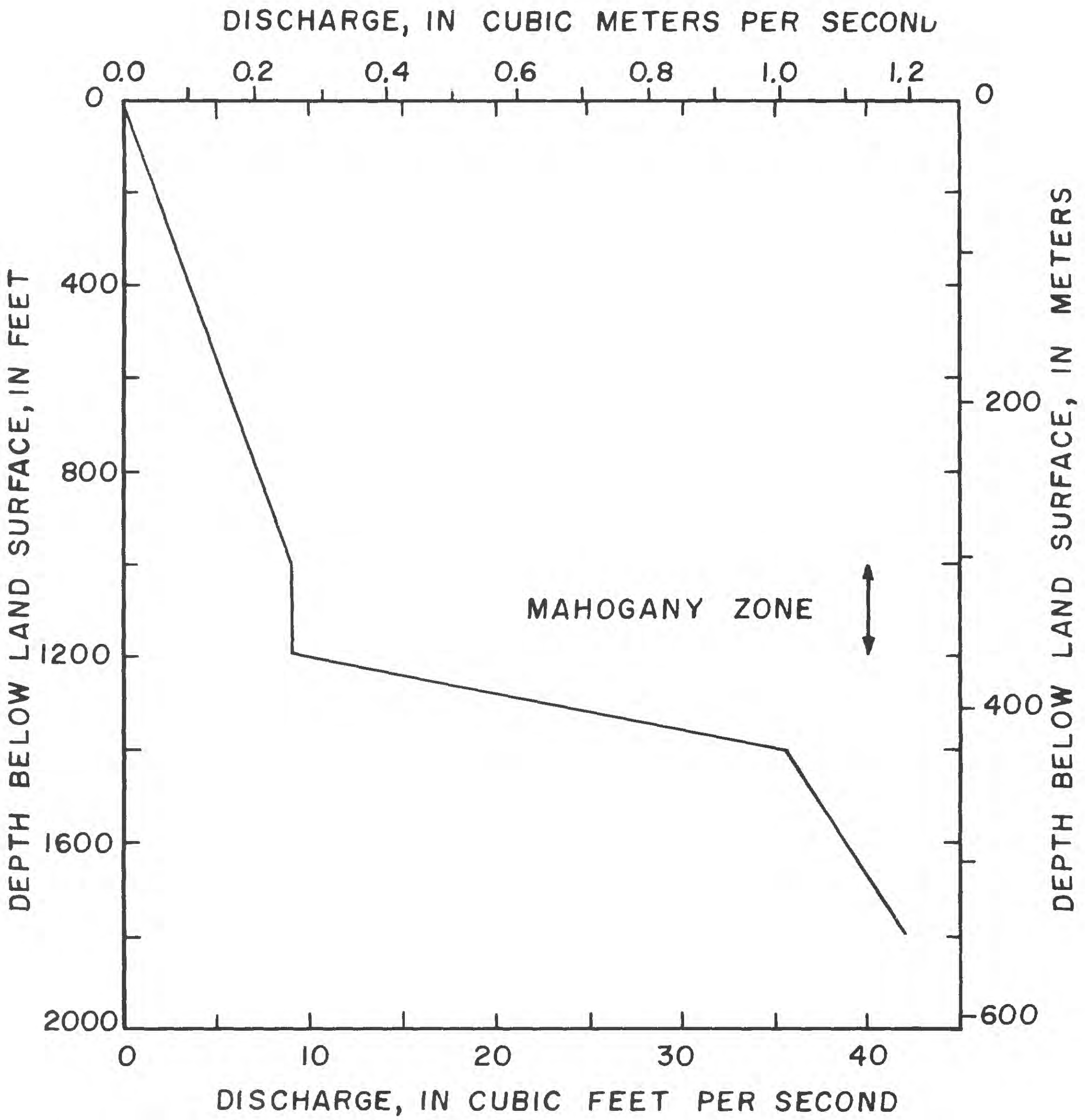

Figure 10.--Graph showing discharge required to dewater a mine shaft at site 1.

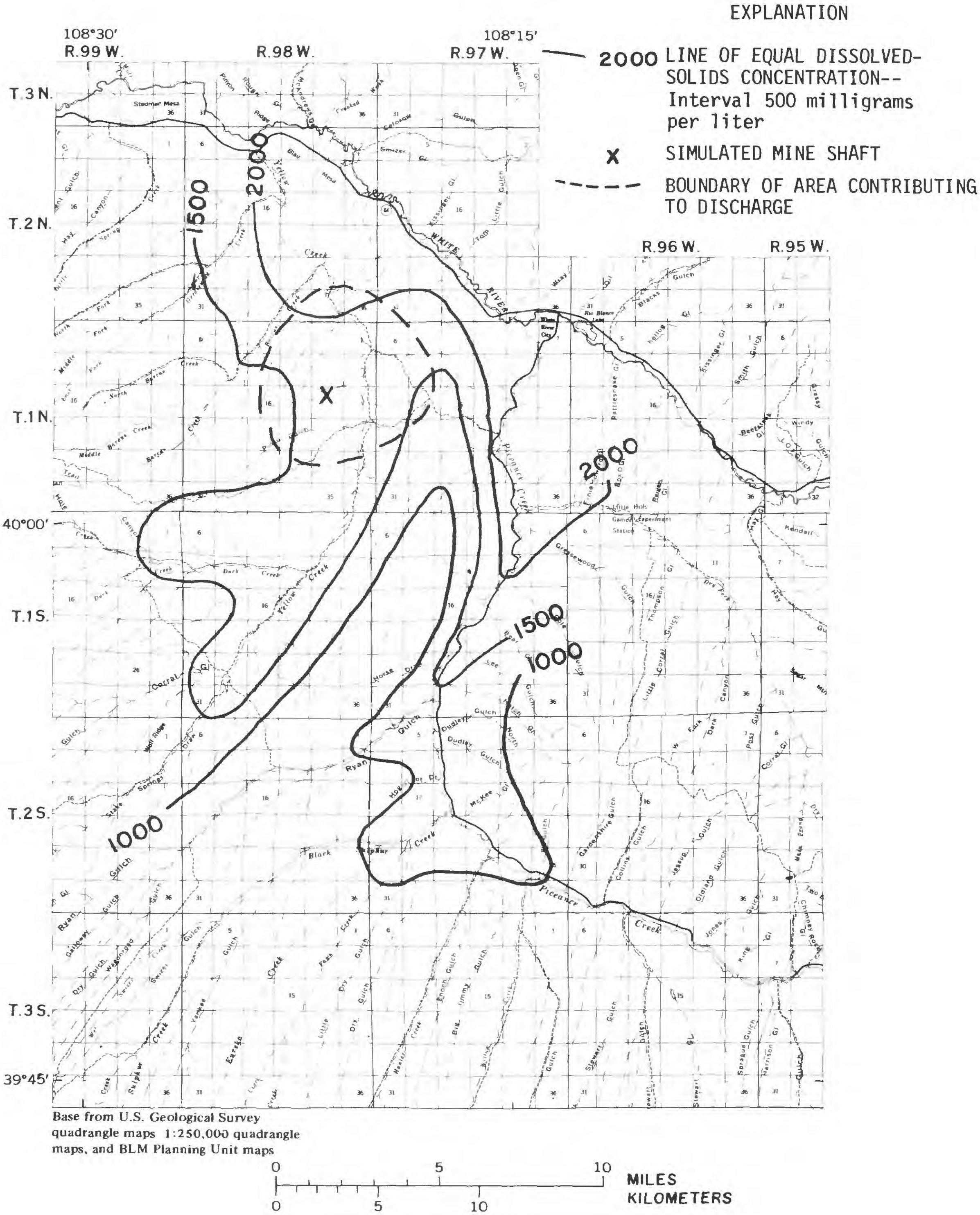

Figure 11.--Map showing dissolved-solids concentration in the upper aquifer and area contributing to discharge from a mine shaft at site 1.

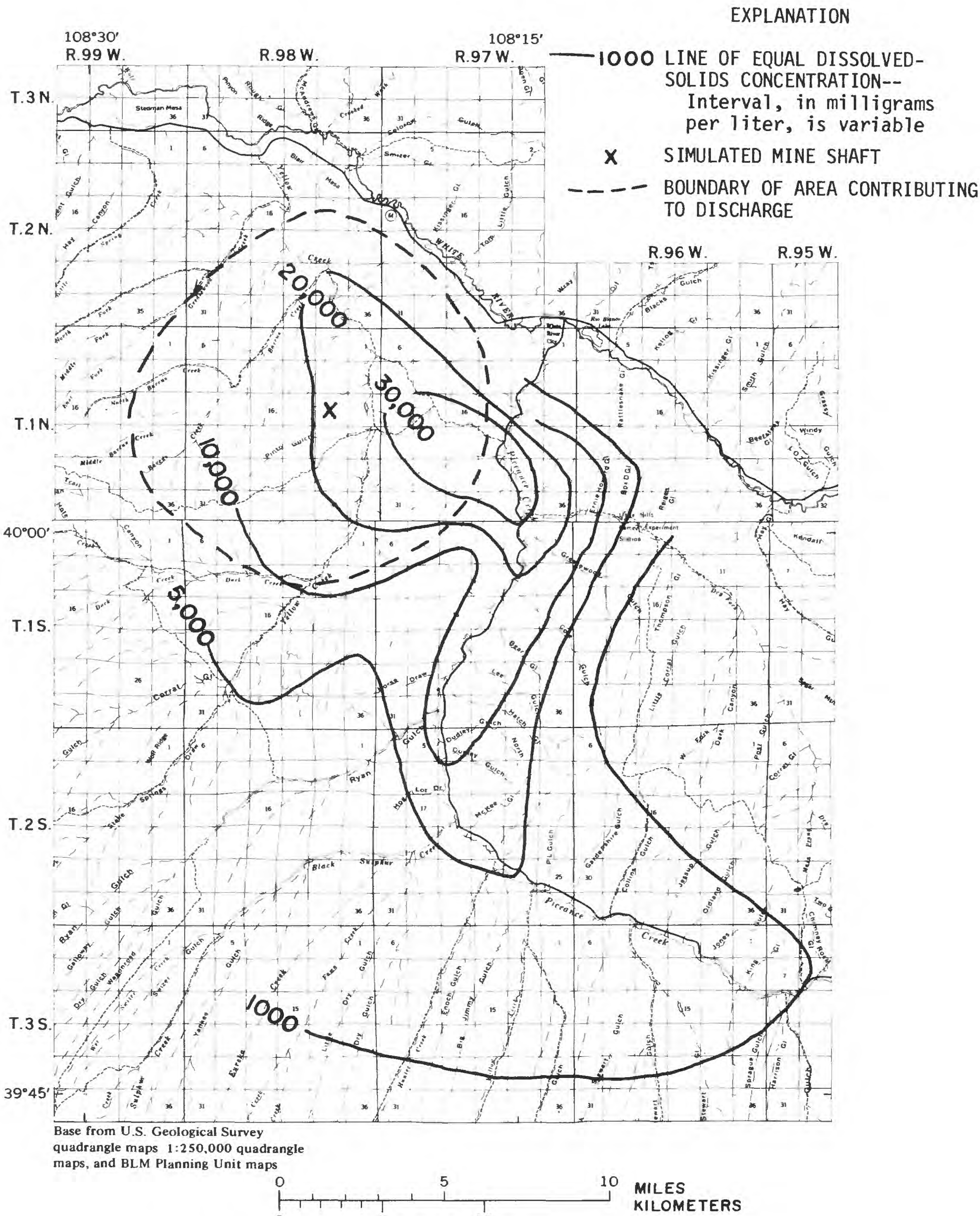

Figure 12.--Map showing dissolved-solids concentration in the lower aquifer and area contributing to discharge from a mine shaft at site 1.

The computed discharge for the mine shaft at site 2 at a depth of 535 m (1,750 ft) is about 0.57 m^3/s (20 ft^3/s) as shown on figure 13. The area of the cone of depression after 87 days of construction is superimposed on the map of dissolved-solids concentration for each aquifer in figures 14 and 15. The concentration of dissolved solids in the water produced by the shaft is estimated to be 1,000 mg/L from the upper aquifer and 5,000 mg/L from the lower aquifer.

Site 3

The area of site 3 is tributary to Yellow Creek 20.9 km (13 mi) upstream from its confluence with the White River (fig. 8). All streams in the vicinity of the site are intermittent. Waste water produced at the site could be contained in one of several tributaries to Yellow Creek. Spent shale could be disposed of in either Pinto Gulch or the unnamed tributary (fig. 8) which is partly on the site.

The location of the simulated mine shaft at site 3 is shown on figure 8. Construction of the shaft will penetrate 425 m (1,400 ft) of saturated section before reaching the high-resistivity zone at a depth of about 460 m (1,500 ft). The upper aquifer is 185 m (600 ft) thick and the transmissivity is about 13 m^2/d (140 ft^2/d). The lower aquifer is 185 m (600 ft) thick with a transmissivity of 64 m^2/d (670 ft^2/d). The storage coefficients are estimated to be the same as at site 1.

The computed discharge for the mine shaft at site 3 is shown on figure 16. At a depth of 460 m (1,500 ft), the discharge from the shaft is 0.85 m^3/s (30 ft^3/s). The area of the cone of depression after 75 days of construction is superimposed on the dissolved-solids concentration map for each aquifer shown on figures 17 and 18. The concentration of dissolved solids in the water produced during construction of the shaft is estimated to be 1,500-2,000 mg/L from the upper aquifer and 20,000 mg/L from the lower aquifer.

Site 4

The area of site 4 is tributary to both Piceance and Yellow Creeks (fig. 8). All streams in the vicinity of the site are intermittent except Piceance Creek. Waste water produced at the site could be contained in one of several tributaries to Yellow Creek. The unnamed tributary is adjacent to the site and could be utilized for spent-shale disposal. Development at site 4 could affect both Yellow Creek and Piceance Creek.

The location of the simulated mine shaft at site 4 is shown in figure 8. Construction of the shaft will penetrate 490 m (1,600 ft) of saturated section before reaching the high-resistivity zone at a depth of 610 m (2,000 ft). The upper aquifer is 245 m (800 ft) thick with a transmissivity of 25 m^2/d (270 ft^2/d). The lower aquifer is 185 m (600 ft) thick with a transmissivity of 50 m^2/d (540 ft^2/d). The storage coefficients are estimated to be the same as at site 1.

The computed discharge of the mine shaft at site 4 is shown in figure 19. At a depth of 610 m (2,000 ft), the discharge from the shaft is 1.0 m^3/s (35 ft^3/s). The area of the cone of depression after 100 days of construction is superimposed on the map of dissolved-solids concentration for each aquifer on figures 20 and 21. The concentration of dissolved solids in the water produced from the shaft is estimated to be 1,500 mg/L from the upper aquifer and 20,000-30,000 mg/L from the lower aquifer.

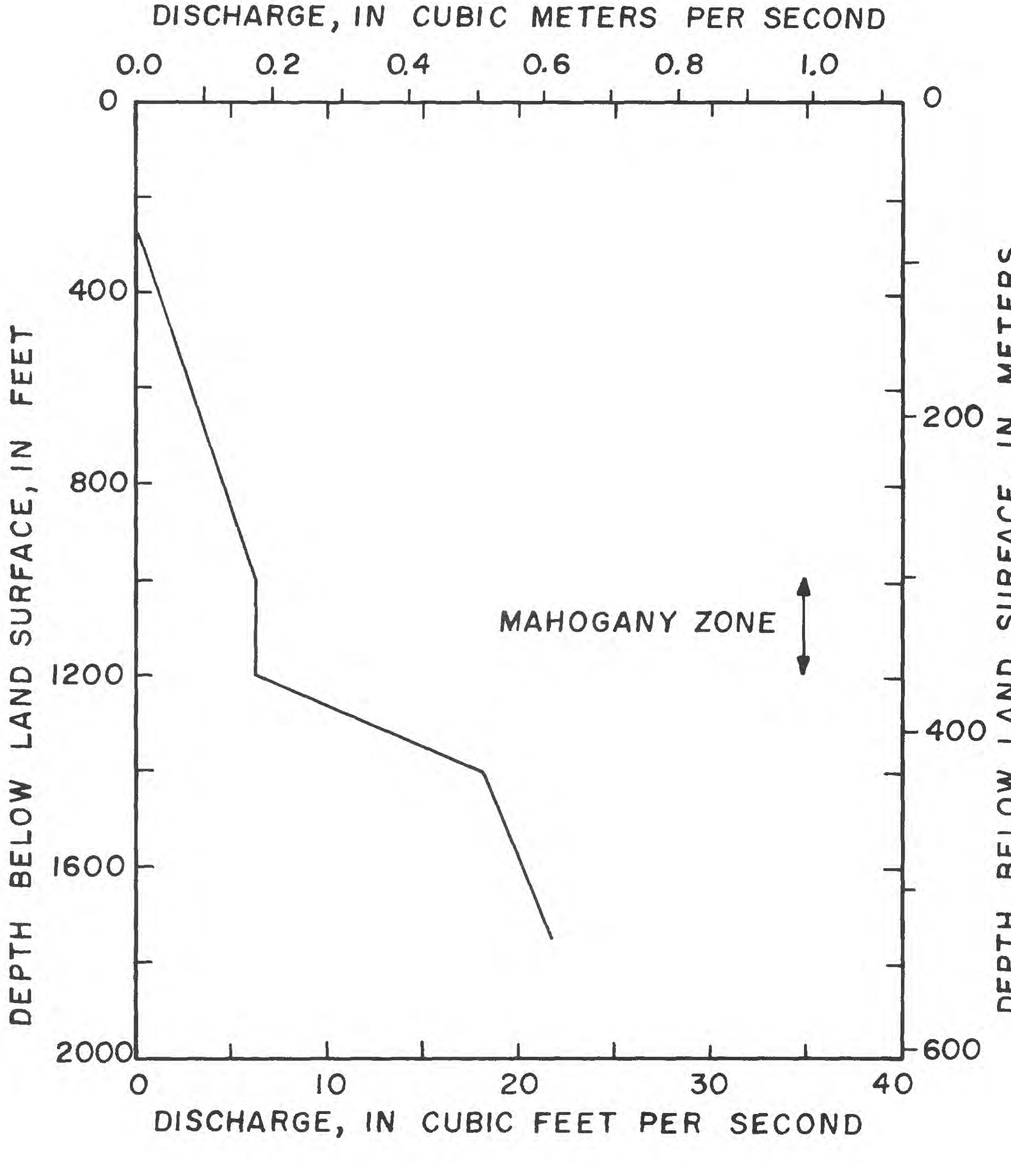

Figure 13.--Graph showing discharge required to dewater a mine shaft at site 2.

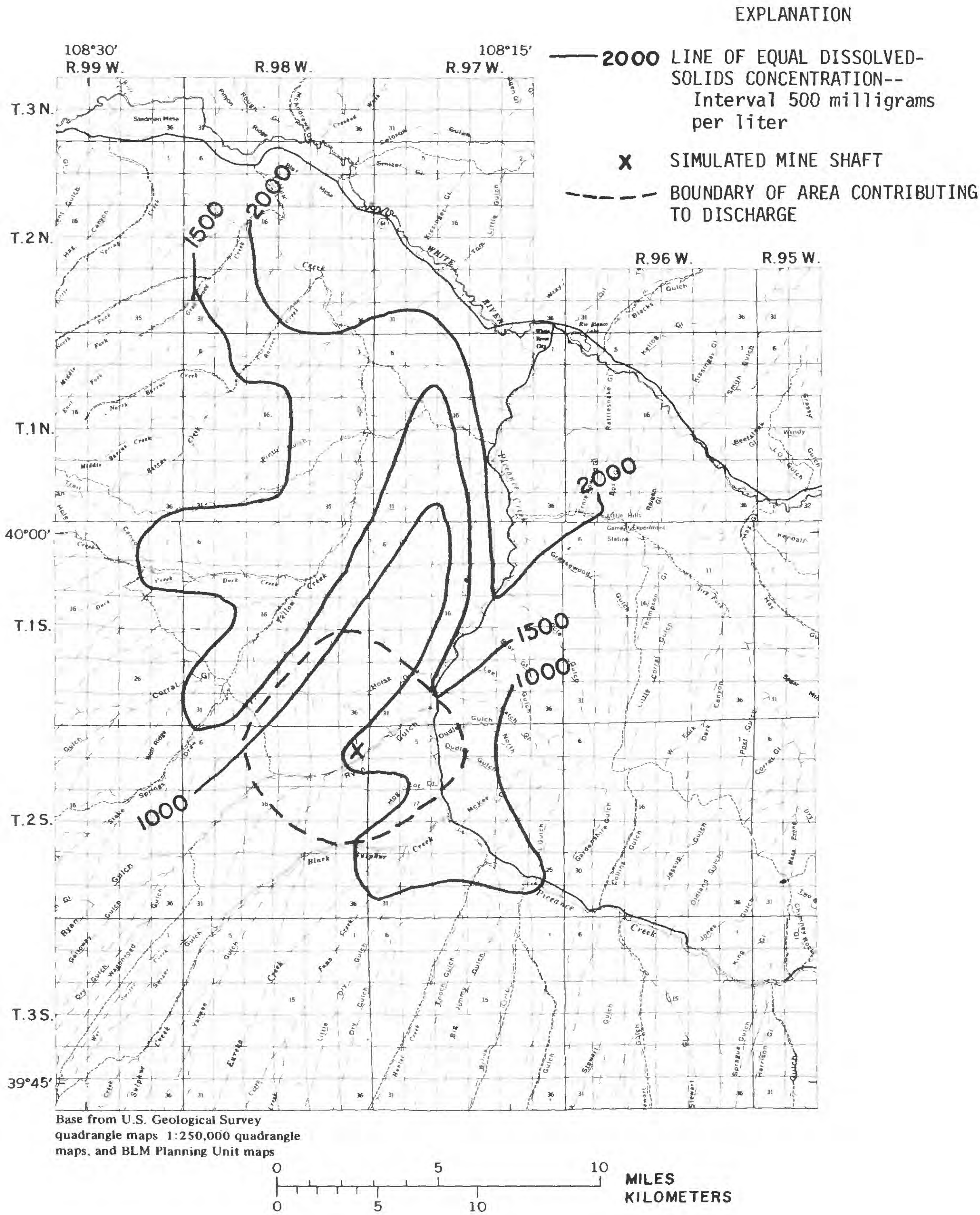

Figure 14.--Map showing dissolved-solids concentration in the upper aquifer and area contributing to discharge from a mine shaft at site 2.

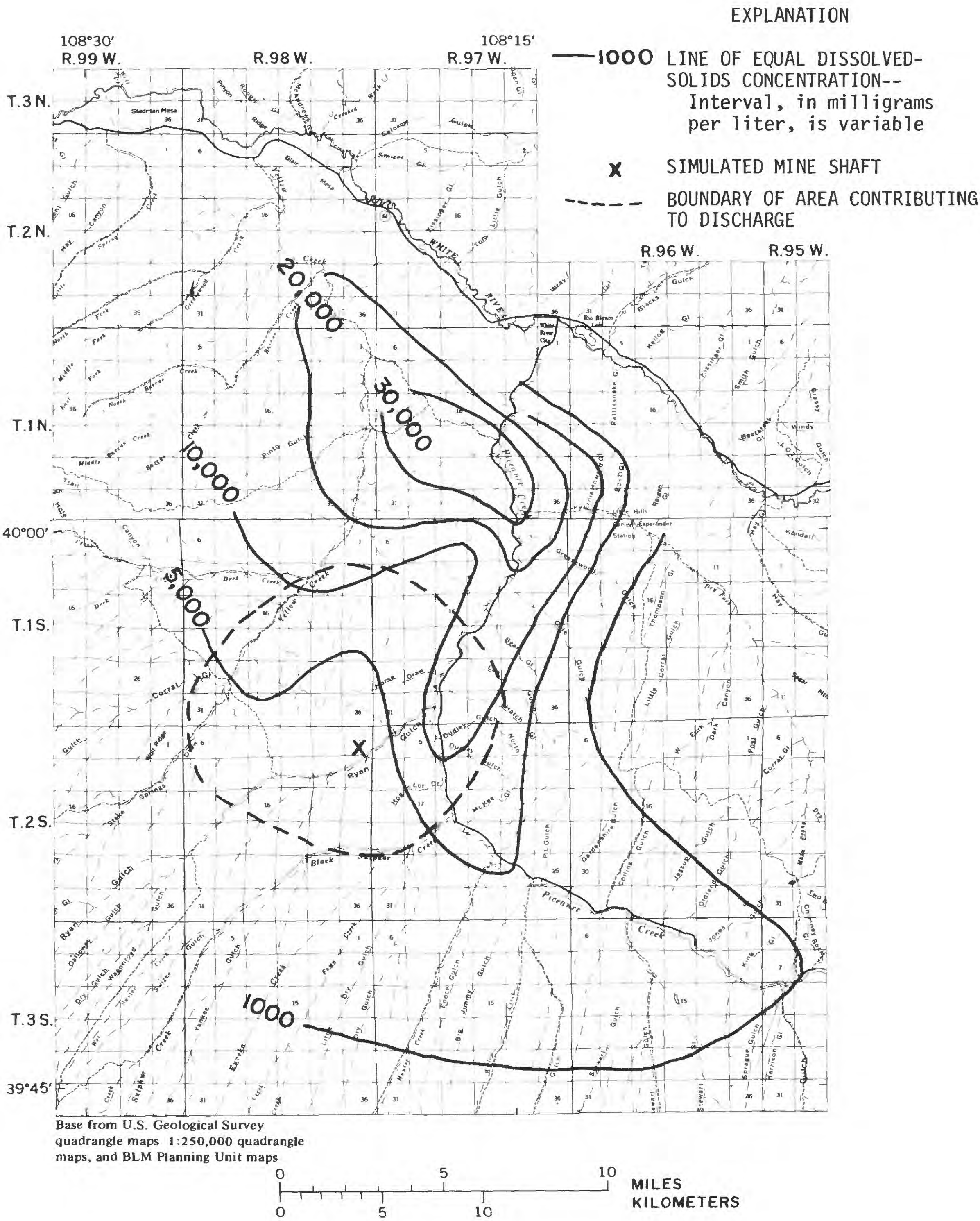

Figure 15.--Map showing dissolved-solids concentration in the lower aquifer and area contributing to discharge from a mine shaft at site 2.

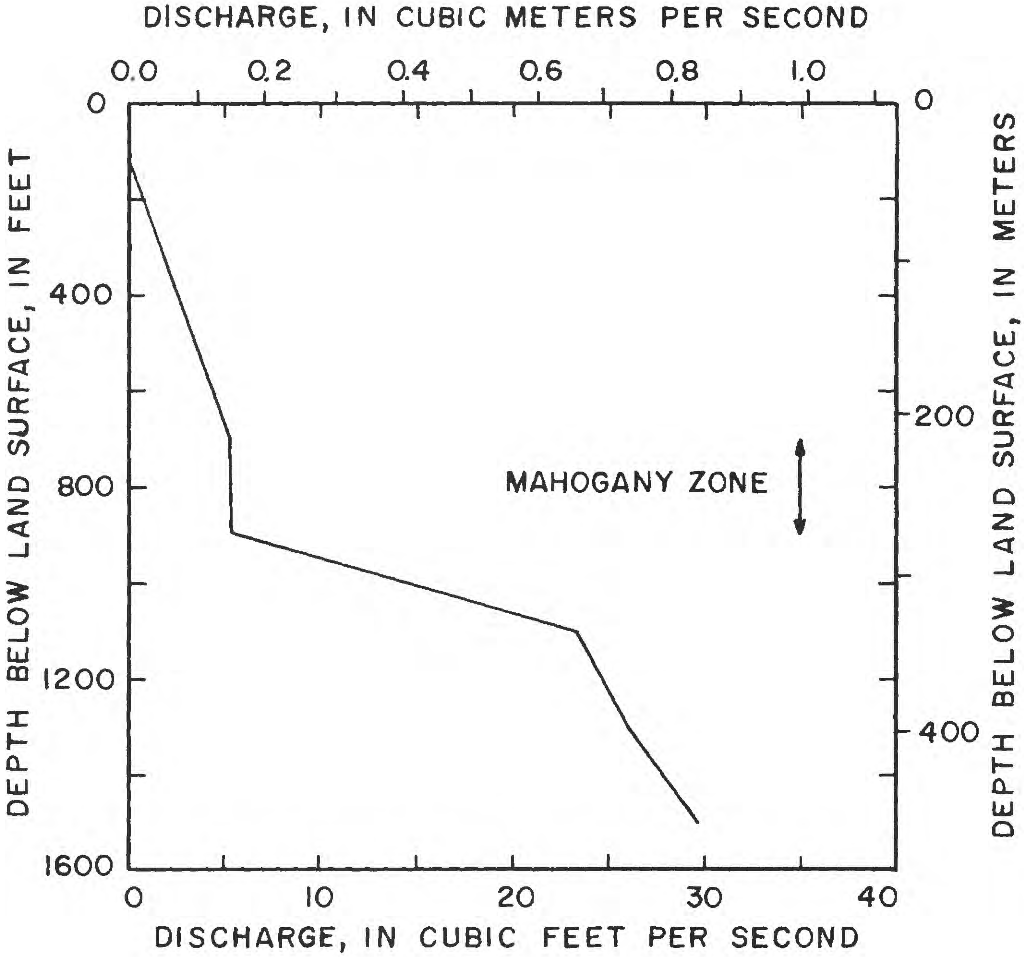

Figure 16.--Graph showing discharge required to dewater a mine shaft at site 3.

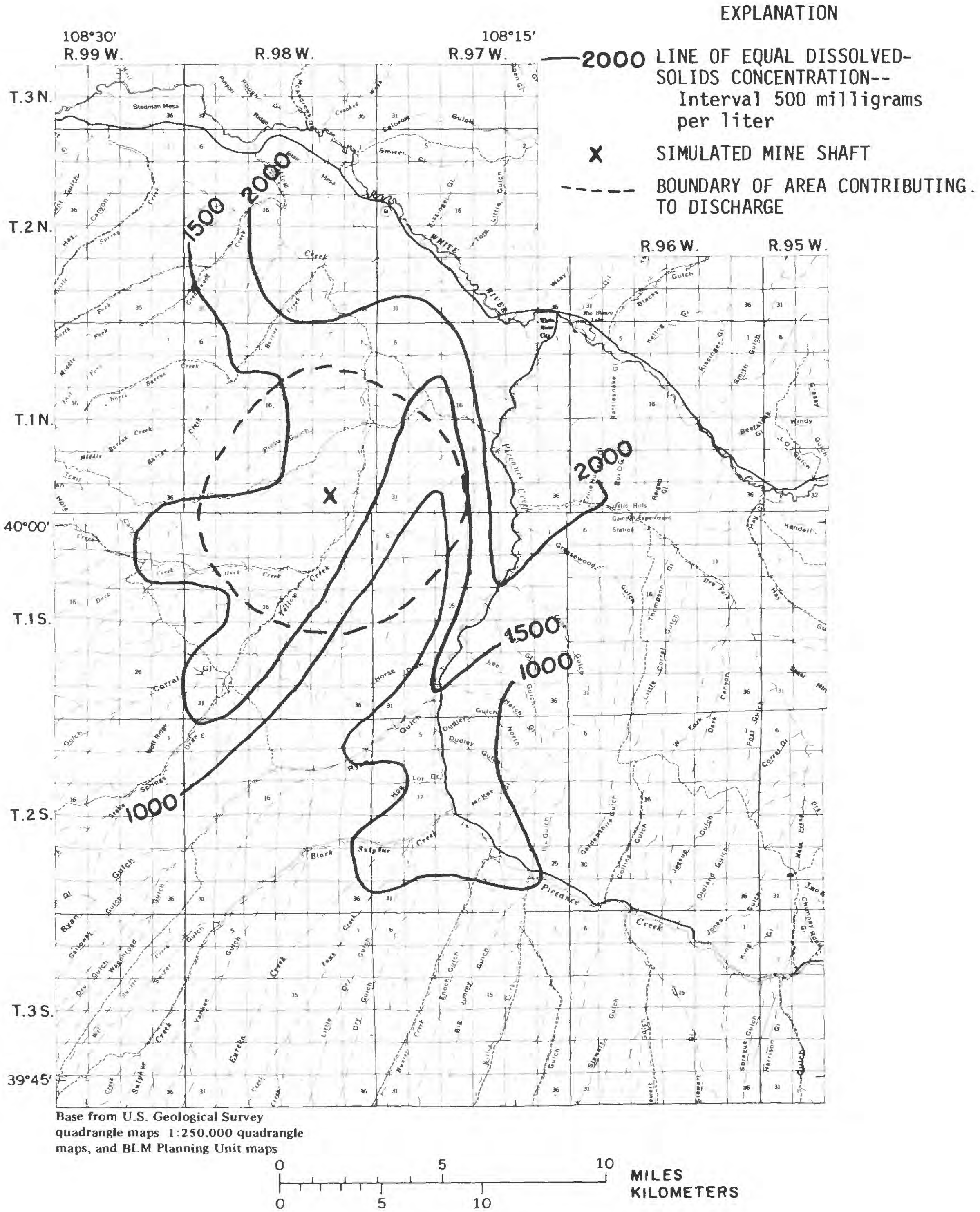

Figure 17.--Map showing dissolved-solids concentration in the upper aquifer and area contributing to discharge from a mine shaft at site 3.

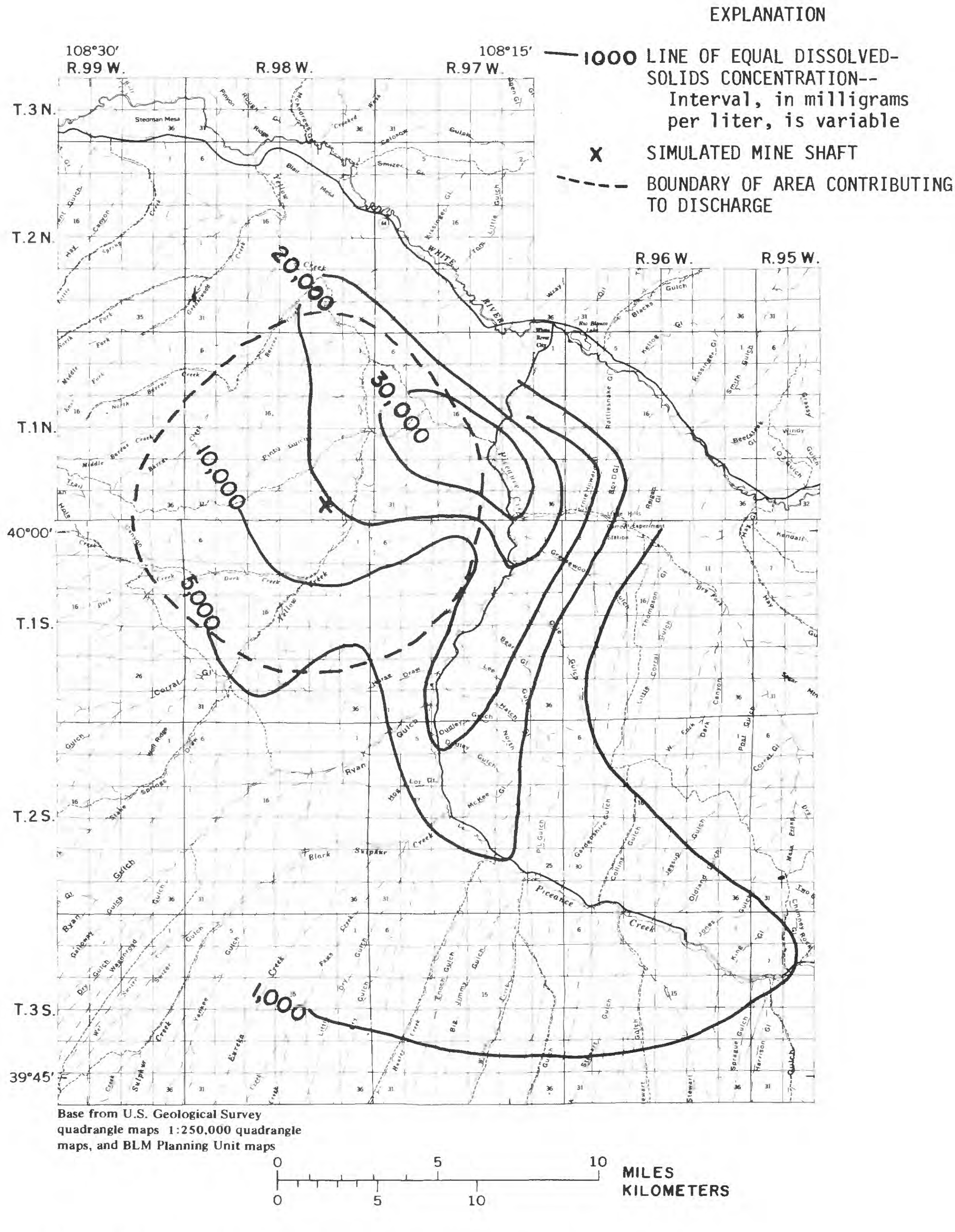

Figure 18.--Map showing dissolved-solids concentration in the lower aquifer and area contributing to discharge from a mine shaft at site 3.

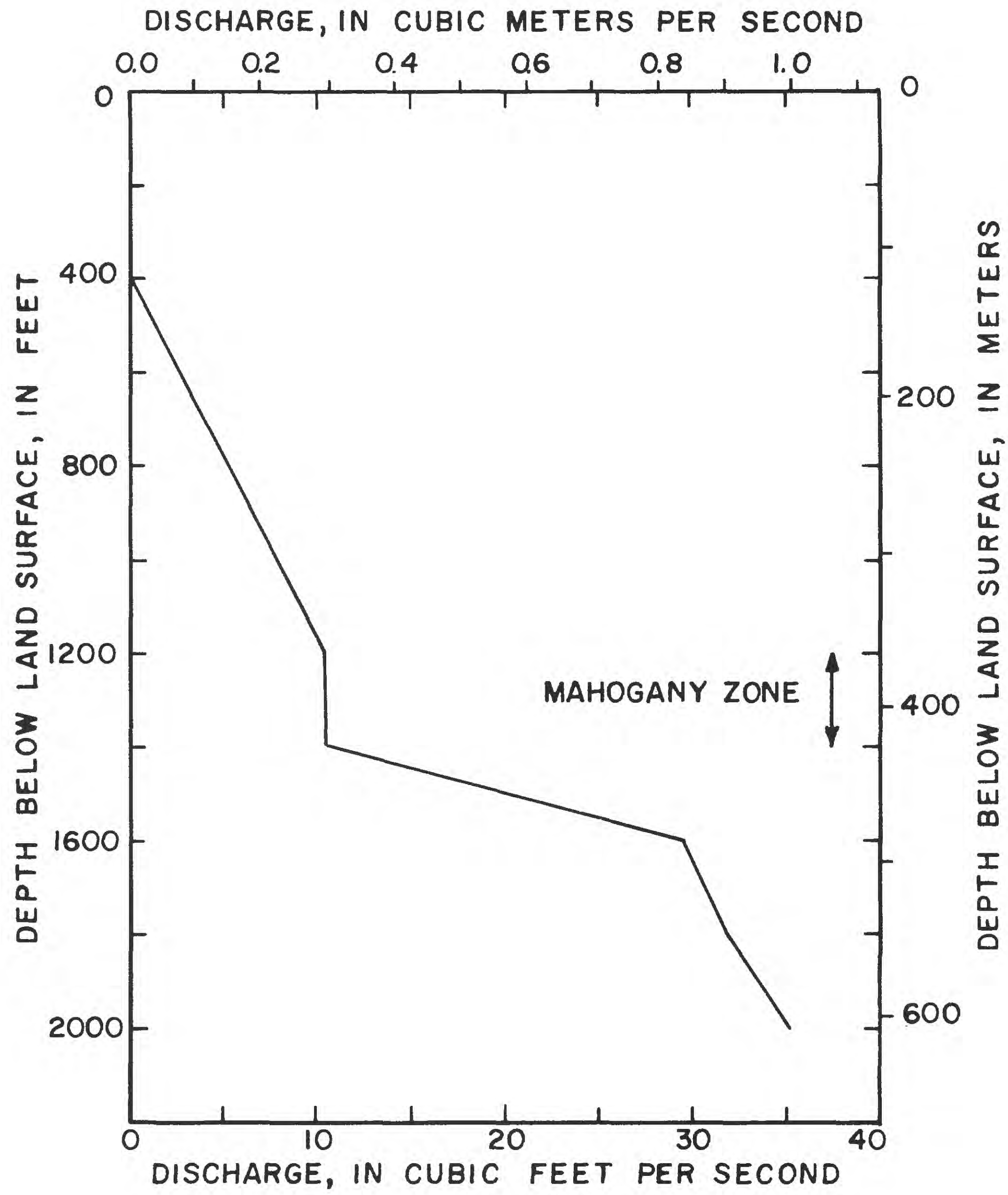

Figure 19.--Graph showing discharge required to dewater a mine shaft at site 4.

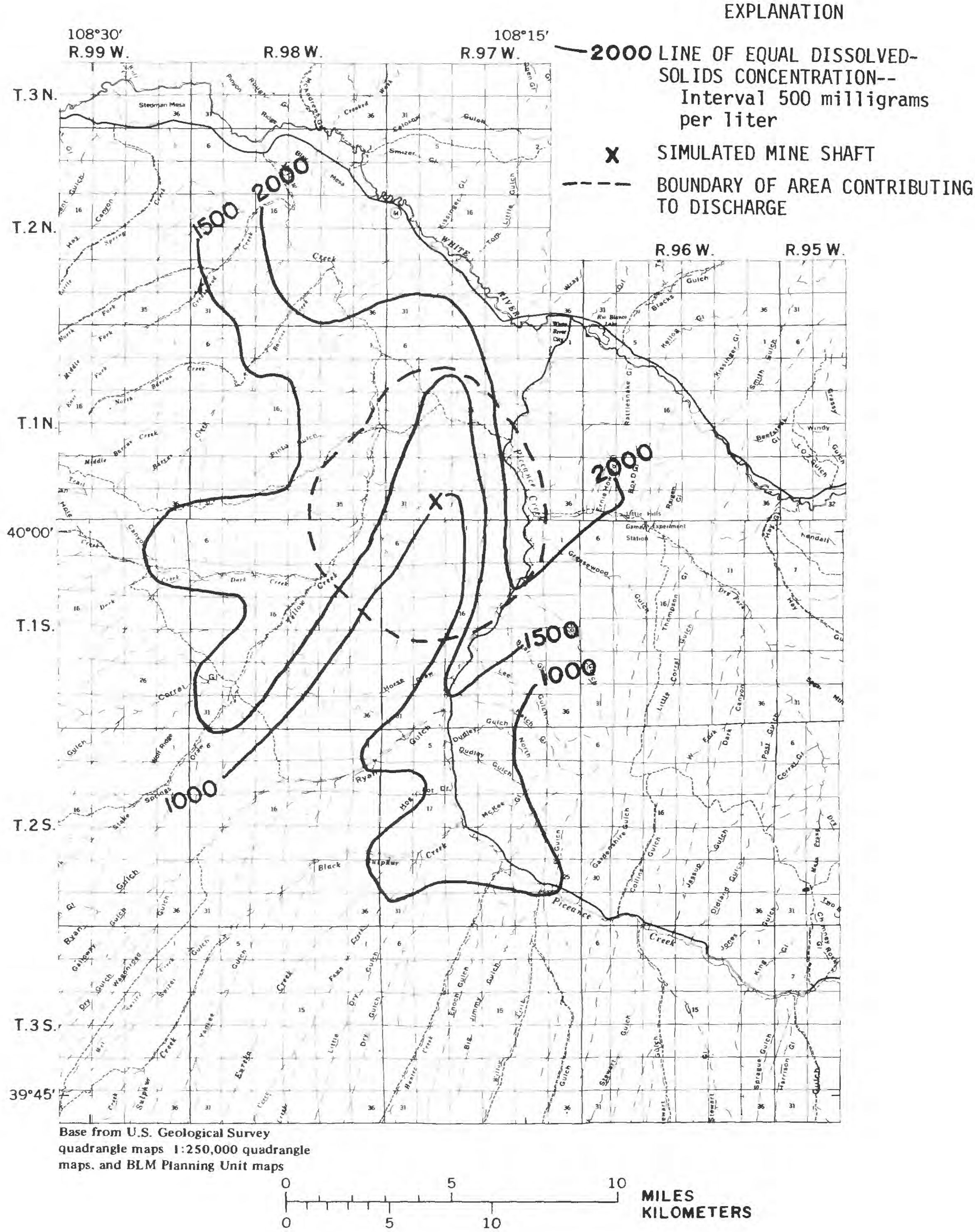

Figure 20.--Map showing dissolved-solids concentration in the upper aquifer and area contributing to discharge from a mine shaft at site 4.

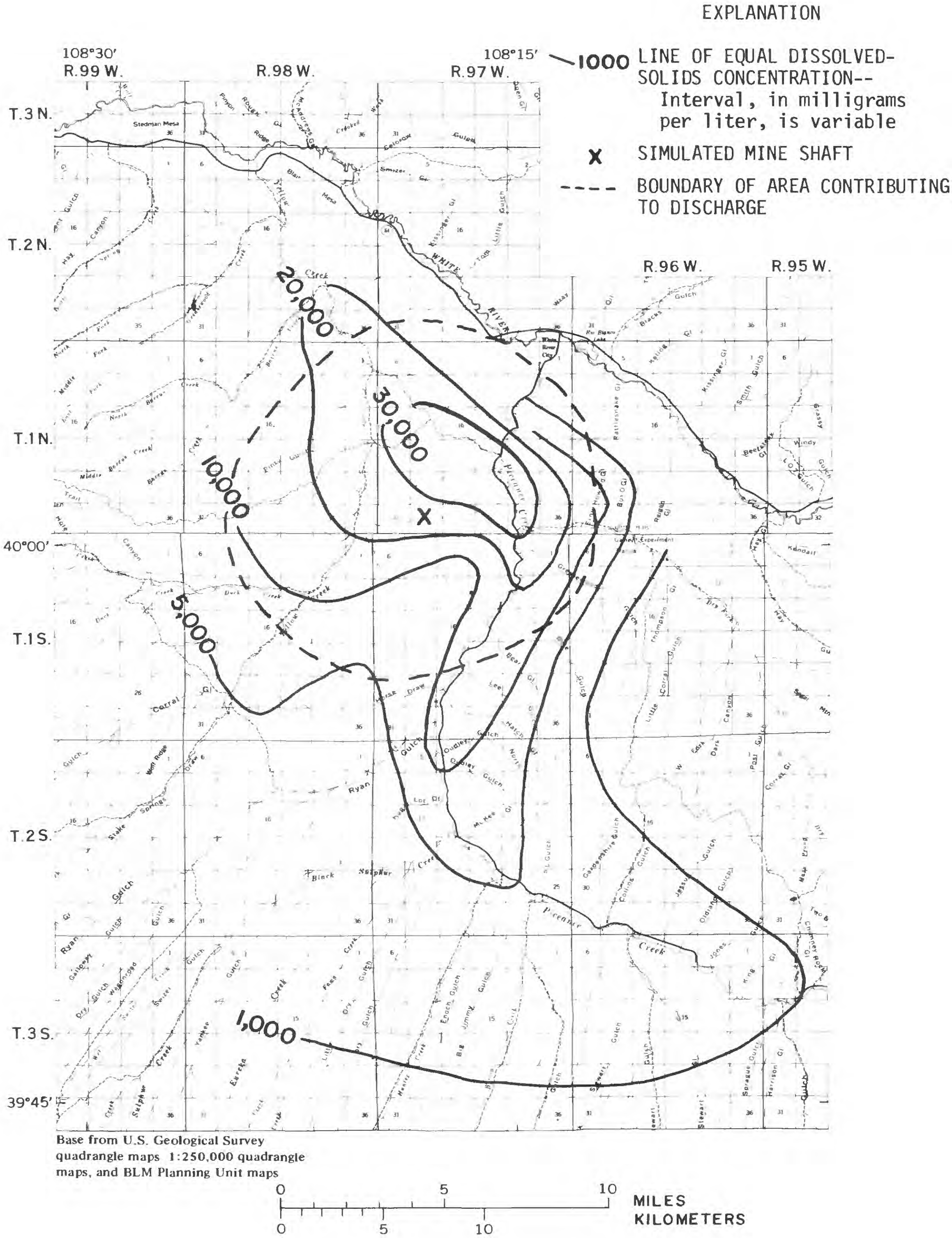

Figure 21.--Map showing dissolved-solids concentration in the lower aquifer and area contributing to discharge from a mine shaft at site 4.

SITE EVALUATIONS

Discharge of waste water during construction of the prototype mine and runoff from spent-shale disposal areas are of primary concern because of the potential impact on the water quality of the White River. Sites 1 and 3 have the advantage of being tributary only to Yellow Creek which is intermittent and reduces the opportunity for waste water or runoff from the sites to reach the White River. However, the discharge of any contaminant from the sites will ultimately reach the White River either through the alluvial aquifer or transport by subsequent runoff. The advantage afforded by the intermittent nature of Yellow Creek is the opportunity for delay and dilution of the contaminant before it reaches the White River. Site 4 also has this advantage if development is limited to that part of the site which is tributary to Yellow Creek.

The area of site 2 is tributary to Ryan Gulch which has only 3.2 km (2 mi) of intermittent stream channel before reaching Piceance Creek. Piceance Creek is a perennial stream and any contaminants reaching it will be carried directly to the White River in less than 1 day.

Waste-water disposal reservoirs can be developed at each of the four proposed sites. However, waste water will infiltrate the surface deposits and reach the ground-water system unless the bottom of the reservoir is sealed.

Unappropriated surface water is not available in the Piceance Creek Basin to meet the demands for oil-shale processing and spent-shale disposal. Unless rights to existing surface water can be acquired, water supplies for each of the proposed sites would have to be developed outside the basin and should be used in conjunction with ground water produced by the mine.

Construction of a mine shaft at sites 1, 3, or 4 will produce 1.4 to 2.1 times the volume of water resulting from a shaft at site 2. For the conditions simulated, about 1.54 hm^3 (1,250 acre-ft) of water would be pumped during construction of a mine shaft at site 2. The concentration of dissolved solids in the discharge water probably will not exceed 5,000 mg/L at site 2; whereas, the concentration of dissolved solids can be expected to equal or exceed 20,000 mg/L at sites 1, 3, and 4. Furthermore, waste water produced at sites 1, 3, or 4 will contain higher concentrations of barium, boron, fluoride, and lithium than at site 2 (Weeks and others, 1974, p. 39-42).

CONCLUSIONS

Water produced during construction of a mine shaft at any of the four proposed sites cannot be released to the surface-water drainage system without degradation of the existing surface-water quality. Consequently, waste water will have to be contained and evaporated if surface-water quality is not to be degraded. Based on hydrologic considerations, site 2 is preferable to sites 1, 3, or 4 if waste material and water are disposed of in Yellow Creek drainage. Water produced during construction at site 2 will be of better quality and smaller quantity than at the other sites. If waste water and rock are disposed of in the unnamed tributary to Yellow Creek, north of site 2, the potential impact of the mine will be minimized. Care needs to be taken to prevent the discharge of waste water and other contaminants to Ryan Gulch and Piceance Creek.

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