GROUND-WATER STUDY 11

by

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1.0 ABSTRACT

Geologic Setting

The coal in the Emery coal field occurs in a number of beds in the Ferron Sandstone Member of the Mancos Shale of Cretaceous age. The I-coal bed, which is the most important economically, has a maximum thickness of about 30 feet. The Ferron crops out in a series of prominent cliffs along the eastern edge of the Emery coal field and dips 2 to 10˚ to the northeast beneath the land surface. The Ferron consists of a variety of sandstones and siltstone, shale, mudstone, and coal. The Ferron ranges in thickness from about 300 to 850 feet. Traditionally, coal has been mined with underground techniques from the I-coal bed. However, a surface mine has been proposed for the Emery field.

The Ground-Water System

The complete thickness of the coal-bearing Ferron Sandstone Member usually is saturated with water a short distance downdip from the outcrop area. Recharge to the Ferron sandstone aquifer is mainly subsurface inflow from the west. The aquifer receives small amounts of recharge from the 8 inches of average annual precipitation on the outcrop area and from leakage from underlying and overlying rocks. Water is discharged from the Ferron by dewatering of an underground mine, by wells, by leakage to underlying and overlying rocks, by leakage along streams, by springs and seeps, and by phreatophytes.

Downdip from the outcrop area, transmissivity of the Ferron ranges from about 200 to 700 square feet per day. Water in the Ferron is confined in most areas, and the storage coefficient ranges from about 3×10^{-6} to 2×10^{-3}.

There are significant hydraulic-head differences in the Ferron Sandstone aquifer. Downdip from the outcrop area, head in the Ferron usually increases with depth and usually is higher than the water table in overlying rocks.

The concentration of dissolved solids in the Ferron ranges from about 750 to 8,000 milligrams per liter. Deterioration of water quality usually is due to increased concentrations of dissolved sodium and sulfate.

Probable Hydrologic Consequences of Mining

Identified changes in the ground-water system caused by dewatering of an underground mine include dewatering of much of the Ferron sandstone aquifer near the mine and both improvement and deterioration of water quality in the aquifer. Dewatering of a proposed surface mine would have the same effects on the aquifer and, in addition, the base flow and water quality in a stream would be changed. A computer model of the ground-water system was used to make semiquantitative predictions of hydrologic effects of the surface mine.

Ground-Water Monitoring

A network of observation wells would be needed near mines to monitor changes in potentiometric surfaces and water quality in the Ferron Sandstone aquifer. In addition, the quantity and the quality of water discharged from mines would need to be monitored.

2.0 GEOLOGIC SETTING

2.1 OCCURRENCE OF COAL

COAL IN THE EMERY FIELD OCCURS IN SEVERAL BEDS

Coal in the Ferron Sandstone Member of the Mancos Shale can be recovered by both underground and surface mining.

The total coal resource in the Emery coal field (fig. 2.1-1) is estimated to be 2.06 billion tons (2). The coal occurs in several beds in the Ferron Sandstone Member of the Mancos Shale of Cretaceous age. As shown in figure 2.1-2, five major beds of coal occur in the Ferron; thin, localized beds of coal are not shown. The coal beds are labeled alphabetically, in ascending stratigraphic order, according to the scheme proposed by Lupton (7). The I-coal bed, which is the most important economically, has a maximum thickness of about 30 feet.

Traditionally, coal has been mined by underground methods in the Emery field. The first recorded mining was of the I-coal bed at the Emery Mine (formerly the Browning Mine) in 1881. Activity at the Emery Mine was irregular until 1937 but has been steady since (2). Coal from the I bed also has been mined at the Dog Valley Mine since 1930. About 99 million tons of coal in the Emery field are recoverable by surface mining (1), and a surface mine has been proposed near the Emery Mine.

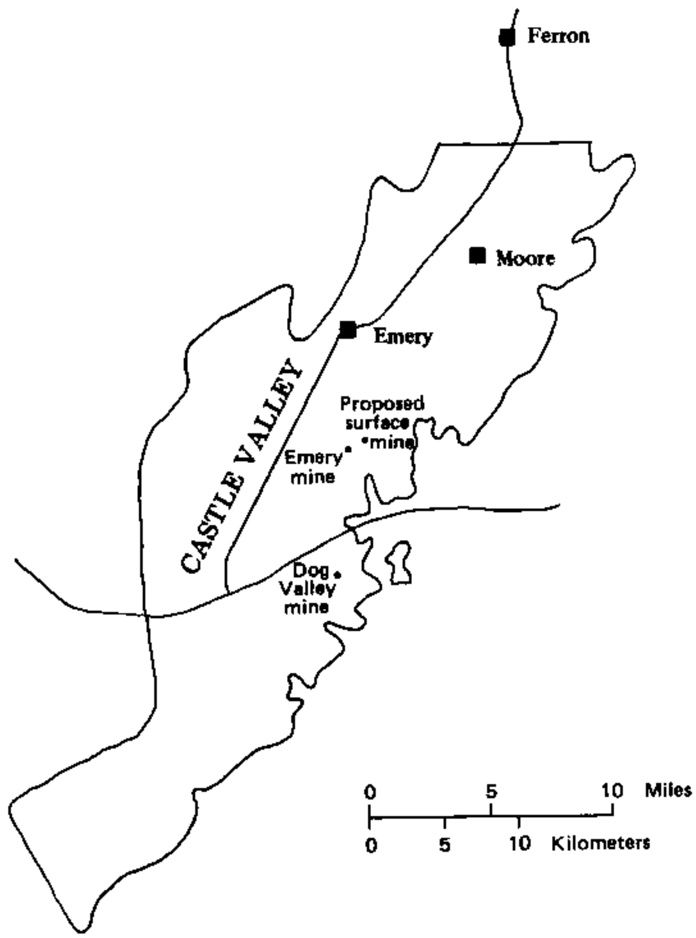

Figure 2.1-1.— Outline of Emery coal field.
(Modified from Ryer, 1981, fig. 1.)

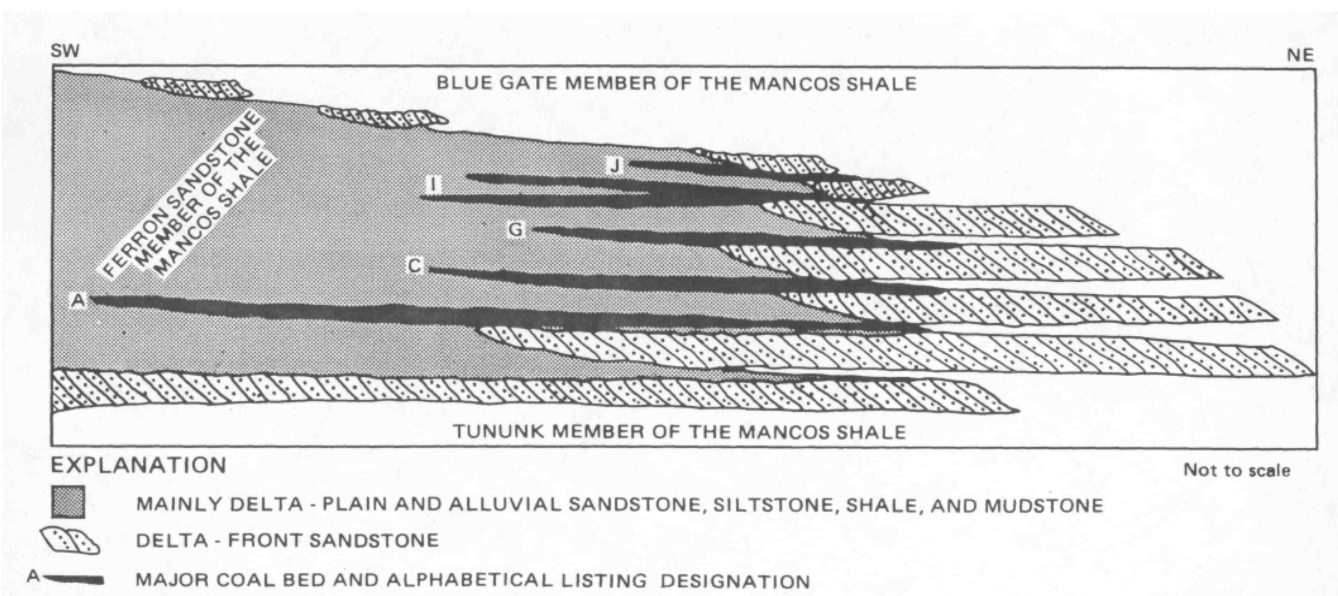

Figure 2.1-2.— Diagrammatic cross section of the Ferron Sandstone Member of the Mancos Shale.
(Modified from Ryer, 1981, fig. 13.)

2.0 GEOLOGIC SETTING

2.2 EXTENT AND THICKNESS OF THE FERRON SANDSTONE MEMBER

OUTCROP AREAS OF GEOLOGIC UNITS ARE MAPPED

The coal-bearing Ferron Sandstone Member ranges in thickness from about 300 to 850 feet in the Emery coal field.

Outcrop areas of the coal-bearing Ferron Sandstone Member and other geologic units in the Emery area are shown in figure 2.2-1. The Ferron crops out in a series of prominent cliffs along the eastern edge of the Emery coal field and dips 2 to 10˚ to the northwest beneath the land surface. Along the outcrop, the Ferron ranges in thickness from about 300 feet in the northern part of the Emery field to about 850 feet in the southern part (5). The Ferron also generally thickens in the subsurface downdip from the outcrop.

The Ferron Sandstone Member consists of massive beds of very fine to medium-grained, delta-front sandstone and a variety of delta-plain and alluvial rock types, mainly very fine grained sandstone, siltstone, shale, mudstone, and coal. The Ferron lies between and intertongues with marine shales in the Tununk and Blue Gate Members of the Mancos Shale. The Tununk and Blue Gate each are several hundred feet thick.

The continuity of the Ferron is broken in the subsurface by the Paradise Valley-Joes Valley fault system. The fault system extends about 60 miles north of the area shown in figure 2.2-1 and about 20 miles south (3). The faults form a graben, and vertical displacement is as much as 3,000 feet in the Emery field (7).

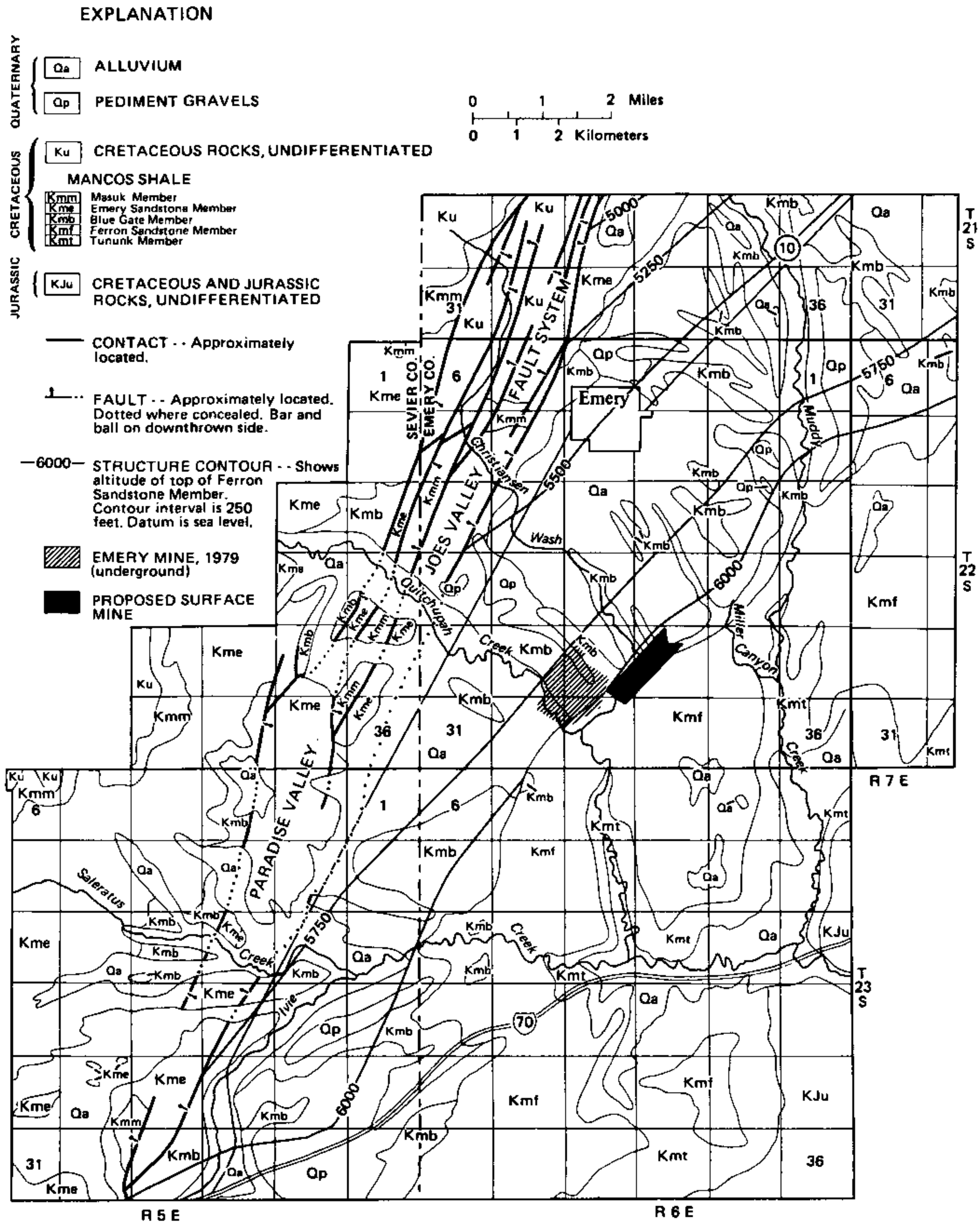

Figure 2.2-1.— Geology of the Emery area.
(Geology from Williams and Hackman, 1971; modified by Lines, 1980; structure contours from Lines and Morrissey, 1981, fig.5.)

3.0 THE GROUND-WATER SYSTEM

3.1 OCCURRENCE, RECHARGE, AND DISCHARGE

THE COAL-BEARING FERRON SANDSTONE MEMBER IS AN AQUIFER

Dewatering of the underground Emery Mine was the largest manmade discharge from the Ferron Sandstone aquifer during 1979.

Records from wells and test holes indicate that the complete thickness of the coal-bearing Ferron Sandstone Member usually is saturated with water within a short distance from the outcrop area. Not all the Ferron is saturated in the outcrop area; much of it is unsaturated at higher altitudes along the outcrop. The Ferron Sandstone Member yields water to wells and the underground Emery Mine, and the unit comprises the Ferron sandstone aquifer.

The Tununk and Blue Gate Members also contain water. Although the shales in these units are relatively impermeable compared with the Ferron Sandstone aquifer, they transmit water and are in hydraulic connection with the Ferron.

Sources of recharge to and discharge from the Ferron Sandstone aquifer in the Emery area are shown in the generalized block diagram (fig. 3.1-1). A complete description of the methods used to measure or estimate rates of recharge and discharge is given in (5). By far the largest source of recharge to the Ferron is subsurface inflow from the west, mainly along the Paradise Valley-Joes Valley fault system. The aquifer also receives small amounts of recharge from precipitation, which averages 8 inches annually on the Ferron outcrop, and from leakage from the Tununk and Blue Gate Members.

Water is discharged from the Ferron Sandstone aquifer by wells, by dewatering of the Emery Mine, by leakage to the Tununk and Blue Gate, by leakage along streams, by springs and seeps, and by transpiration of phreatophytes. By far the largest manmade discharge from the Ferron is the dewatering of the underground Emery Mine, which averaged 0.7 ft^3/s during 1979. Wells that tap the Ferron provide water for the public-water supply at the town of Emery, for coal washing, for stock watering and domestic supplies at ranches, and for a small amount of irrigation.

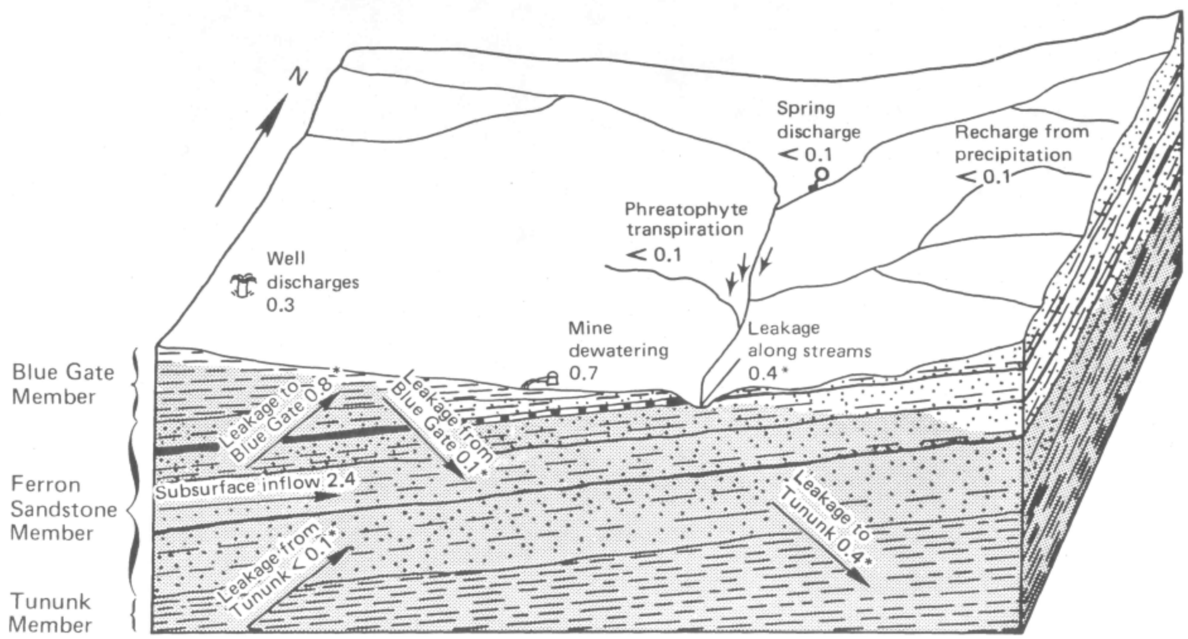

Figure 3.1-1.— Generalized diagram showing sources of recharge to and discharge from the Ferron Sandstone aquifer in the Emery area, 1979. Recharge and discharge rates are in cubic feet per second; an asterisk indicates that rate was calculated by steady-state model simulation. The saturated zone is indicated by the shaded area.
(From Morrissey and others, 1980, fig. 2.)

3.0 THE GROUND-WATER SYSTEM

3.2 AQUIFER TESTS

LABORATORY AND FIELD TESTS CONDUCTED

Porosity and hydraulic conductivity of rocks in the Ferron Sandstone aquifer vary markedly.

Results of laboratory tests of porosity and hydraulic conductivity of cores from the Ferron Sandstone aquifer are summarized in table 3.2-1. The large variation in the porosity and hydraulic conductivity of the sandstone cores probably is due to differences in cementation and compaction. Similar unconsolidated sand would have a porosity of about 40 percent (4), as compared to the average of 16 percent for sandstone in the Ferron. In all sandstone cores from the Ferron, the difference between horizontal and vertical hydraulic conductivities was less than one order of magnitude. Hydraulic conductivities of shale and siltstone cores were much less than those of most sandstones.

Aquifer tests of the Ferron Sandstone aquifer are summarized in table 3.2-2. All tests were conducted where the aquifer was confined. Considering the thickness and lithology of that part of the aquifer tapped by each test well, some calculated transmissivity values agree fairly well with what would be expected from hydraulic conductivities determined in the laboratory. At sites near the Paradise Valley-Joes Valley fault system, the calculated transmissivities of several hundred feet squared per day are larger than would be expected from the laboratory data. This is due to secondary permeability in the aquifer in the form of fractures.

None of the tested wells fully penetrated the Ferron. However, where the Ferron is extensively fractured, thus increasing hydraulic connection in the aquifer, the computed transmissivities fairly accurately represent the transmissivity of the full thickness of the aquifer. Computed transmissivities from most tests that were conducted more than about 2 miles from the Paradise Valley-Joes Valley fault system represent the transmissivity of only part of the aquifer.

Table 3.2-1– Laboratory determination of porosity and hydraulic conductivity of core samples from the Ferron Sandstone aquifer in the Emery coal field. (From Lines and Morrissey, 1983, table 1.)

Location of test hole	Lithology	Depth (feet below land surface)	Porosity (percent)	Hydraulic Conductivity (feet per day)	
				Horizontal	Vertical
SE¼ SE¼ SW¼ sec. 22 ,	S	182	19	8.0×10^{-2}	1.1×10^{-1}
T. 22S., R. 6E.	S	202	18	9.8×10^{-2}	9.5×10^{-2}
SW¼ NE¼ SW¼ sec. 34 ,	S	84	17	2.5×10^{-1}	2.1×10^{-1}
T. 22S., R. 6E.	S	125	18	4.9×10^{-3}	5.1×10^{-3}
	S	169	10	2.4×10^{-3}	2.3×10^{-3}
	S	181	13	5.6×10^{-2}	4.1×10^{-2}
	Sh	200	—	———	5.5×10^{-6}
SW¼ SE¼ SE¼ sec. 3,	S	9	20	7.7×10^{-1}	3.2×10^{-1}
T. 23S., R. 6E.	S	34	18	1.1×10^{-2}	2.9×10^{-3}
	S	54	14	7.3×10^{-4}	———
	S	164	17	2.7×10^{-2}	6.8×10^{-3}
	S	224	12	7.3×10^{-4}	2.9×10^{-3}
	S	283	20	3.2×10^{-1}	2.6×10^{-1}
NW¼ W¼ NE¼ sec. 5,	S	42	20	8.8×10^{-2}	1.6×10^{-1}
T. 24S., R. 6E.	Slt	92	11	3.2×10^{-5}	2.9×10^{-6}
	Slt	151	16	7.3×10^{-4}	$3,2 \times 10^{-5}$
	S	342	15	9.8×10^{-3}	4.6×10^{-3}

Table 3.2-2.– Summary of aquifer tests of the Perron sandstone aquifer 1978-79. (Modified from Lines and Morrissey, 1981, table 2.)

[Method of test analysis: C, constant drawdown (Lohman, 1972, p. 23-26); L, Hantush modified method for leaky confined aquifer (Lohman, 1972, p. 32-34.); R, straight-line recovery method (Lohman, 1972, p. 26 and 27.)]

Location of discharging well	Time-weighted average discharge (gallons per minute)	Duration of test (minutes)	Depth of well below land surface (feet)	Depth to first opening in well (feet)	Distance to observation well from discharging well (feet) and direction	Transmissivity (feet squared per day)	Storage coefficient	Method of test analysis	Remarks
NW ¼ NE ¼ SW ¼ sec. 4, T. 22 S., R. 6E.	51	150	1,614	1,586	——	800 600	([1]) ——	C R	Open hole below 1,586 feet in basal section of Ferron Sandstone aquifer
SW¼ W¼ NE¼ sec. 17, T. 22S., R. 6E.	176	310	1,543	1,386	——	400 600	([1]) ——	C R	Taps basal section of Ferron Sandstone aquifer
Do.	3	120	1,100	1,040	——	30	——	R	Expandable packer set at 1,040 feet; open hole below in upper section of Ferron Sandstone aquifer
SE ¼ SE¼ SW¼ sec. 22, T. 22S., R. 6E.	10	1,500	275 270	100 230	—— 375, northwest	10 20	—— 2 x 10^{-3}	R L	Both wells tap upper section of Ferron sandstone aquifer
NW¼ NW¼ NW¼ sec. 26, T. 22S., R. 6E.	8	1,500	349 300	40 30	—— 174, south	— — 100	—— 7 x 10^{-4}	— L	Both wells tap entire upper section and part of basal section of Ferron sandstone aquifer
NW¼ W¼ SW¼ sec. 27, T. 22S., R. 6E.	4	40	380	310	——	100	——	R	Open hole below 310 feet in basal section of Ferron Sandstone aquifer
Do.	3	1,500	158 150	118 75	—— 206, north	40 100	—— 8 x 10^{-4}	R L	Both wells tap upper section of Ferron sandstone aquifer
NW¼ NE ¼ SE ¼ sec. 31, T. 22S., R. 6E.	13	3,065	406	360	——	200	——	R	Taps upper section of Ferron Sandstone aquifer
NW ¼ NW ¼ NW ¼ sec. 32, T. 22S., R. 6E.	16	1	280 280 282 240 245	225 —— 160 200 205	—— 480, north 695, northwest 480, southwest 890, southwest	100 50 400 90 60	—— 1 x 10^{-5} 1 x 10^{-5} 3 x 10^{-6} 3 x 10^{-5}	R L L L L	All wells tap basal section of Ferron sandstone aquifer

([1]) Storage coefficient could not be determined because the effective well radius was unknown, due to fracturing.

3.0 THE GROUND-WATER SYSTEM

3.3 TRANSMISSIVITY AND STORAGE COEFFICIENT

TRANSMISSIVITY AND STORAGE IN THE FERRON ARE DEFINED

Transmissivity of the Ferron Sandstone aquifer downdip from the outcrop area ranges from about 200 to 700 ft^2/d; storage coefficient ranges from about 3×10^{-6} to 2×10^{-3} where the aquifer is confined.

Transmissivity of the Ferron Sandstone aquifer in the Emery area is shown in figure 3.3-1. The transmissivity map was constructed on information from aquifer tests, lithology, hydraulic conductivity and estimates of saturated thickness. Because of secondary permeability (fractures) and the nonhomogeneous nature of the aquifer, the lines of equal transmissivity are considered to be approximate. Calibration of a three-dimensional digital-computer model of the aquifer indicated that the aquifer was simulated most accurately when transmissivity north of about the line of 200 ft^2/d, in figure 3.3-1, was reduced by 10 to 30 percent (5).

Downdip from the outcrop area, transmissivity of the Ferron ranges from about 200 to 700 ft^2/d and increases towards the Paradise Valley-Joes Valley fault system. Transmissivity is generally less than 200 ft^2/d in the outcrop area, with the decrease mainly due to the decrease in saturated thickness of the aquifer.

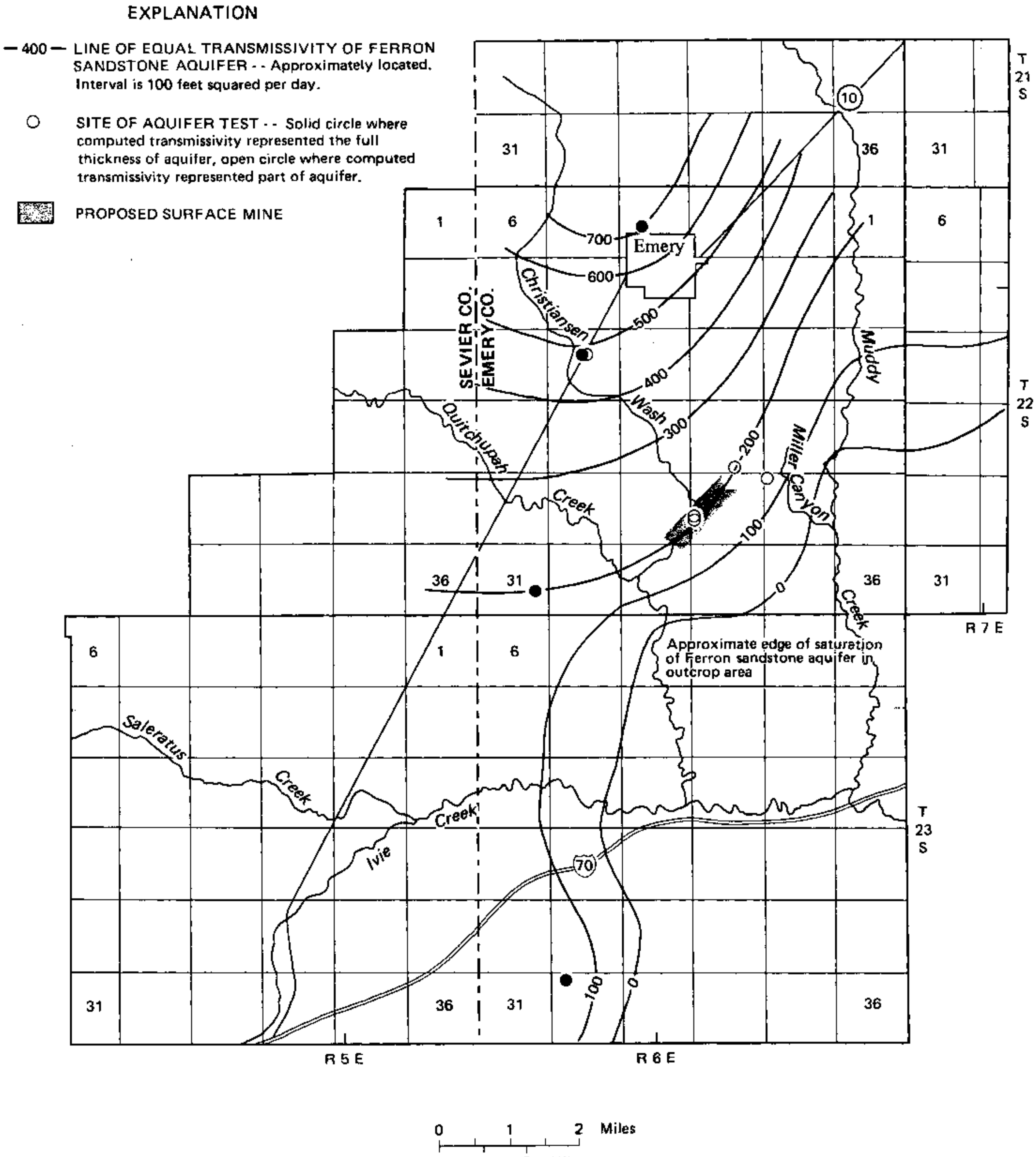

Figure 3.3-1.— Transmissivity of the Ferron Sandstone aquifer in the Emery area. (From Lines and Morrissey, 1983, fig. 7.)

3.0 THE GROUND-WATER SYSTEM

3.4 POTENTIOMETRIC SURFACES OF FERRON SANDSTONEAQUIFER

HYDRAULIC HEAD IN THE FERRON VARIES AREALLY AND WITH DEPTH

Downdip from the Ferron outcrop, head in the aquifer usually increases with depth; in the outcrop area, head decreases with depth.

Potentiometric surfaces of the basal section of the Ferron Sandstone aquifer (below the A-coal bed) and of the upper section of the aquifer (above the base of the I-coal bed) are shown in figures 3.4-1 and 3.4-2. The potentiometric surface varies appreciably with depth in the aquifer. Downdip from the Ferron outcrop, hydraulic head in the aquifer generally increases with depth and usually is higher than the water table in the Blue Gate Member; thus, water from the Ferron leaks into the Blue Gate. In the Ferron outcrop area where water from the Ferron leaks downward into the underlying Tununk Member, and where a small amount of recharge is received from precipitation, head in the aquifer decreases with depth.

In addition to vertical movement of water through the aquifer, water moves laterally at approximately right angles to the potentiometric contours. On a regional scale, the strike and dip of beds in the aquifer have little effect on the movement of water. Movement of water is governed instead by the location and altitude of areas of recharge and discharge. In the Emery area, water moves through the aquifer from areas of subsurface recharge in the west and northwest toward areas of manmade discharge and toward areas of natural discharge mainly along the Ferron outcrop.

The potentiometric contours in figures 3.4-1 and 3.4-2 are based on measurements of different accuracy. The potentiometric surface was determined most accurately in tightly cased wells completed only in a part of the aquifer and in uncased test holes where an expandable packer was used to isolate different sections of the aquifer. However, less accurate data from uncased test holes where an expandable packer was not used also were considered in drawing potentiometric contours.

The altitude of the I-coal bed in the underground Emery Mine also was considered in drawing potentiometric contours for the upper section of the aquifer. Observations in the mine indicate that much of the aquifer has been dewatered above the I-coal bed. Water in the mine during 1979 was mostly in those areas farthest downdip, and much of the older mine workings were dry.

The Ferron Sandstone aquifer has yielded hydrogen sulfide, methane, and carbon dioxide gases to some wells in the Emery coal field. When the wells flowed water at the land surface, shut-in water pressures could not be determined accurately because of the gases.

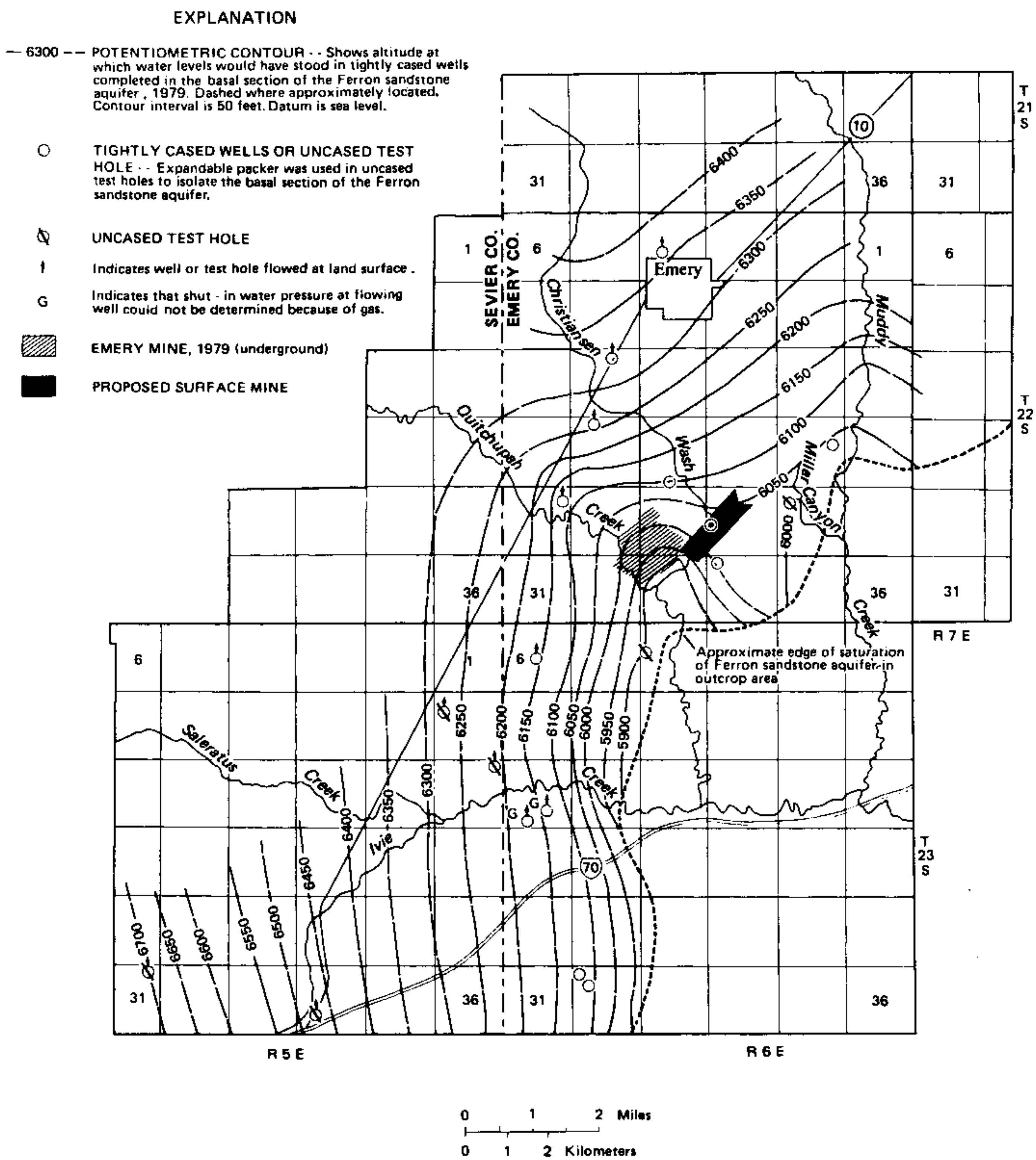

Figure 3.4-1.— Potentiometric surface of the basal section of the Ferron Sandstone aquifer.
(From Lines and Morrissey, 1983, fig. 8.)

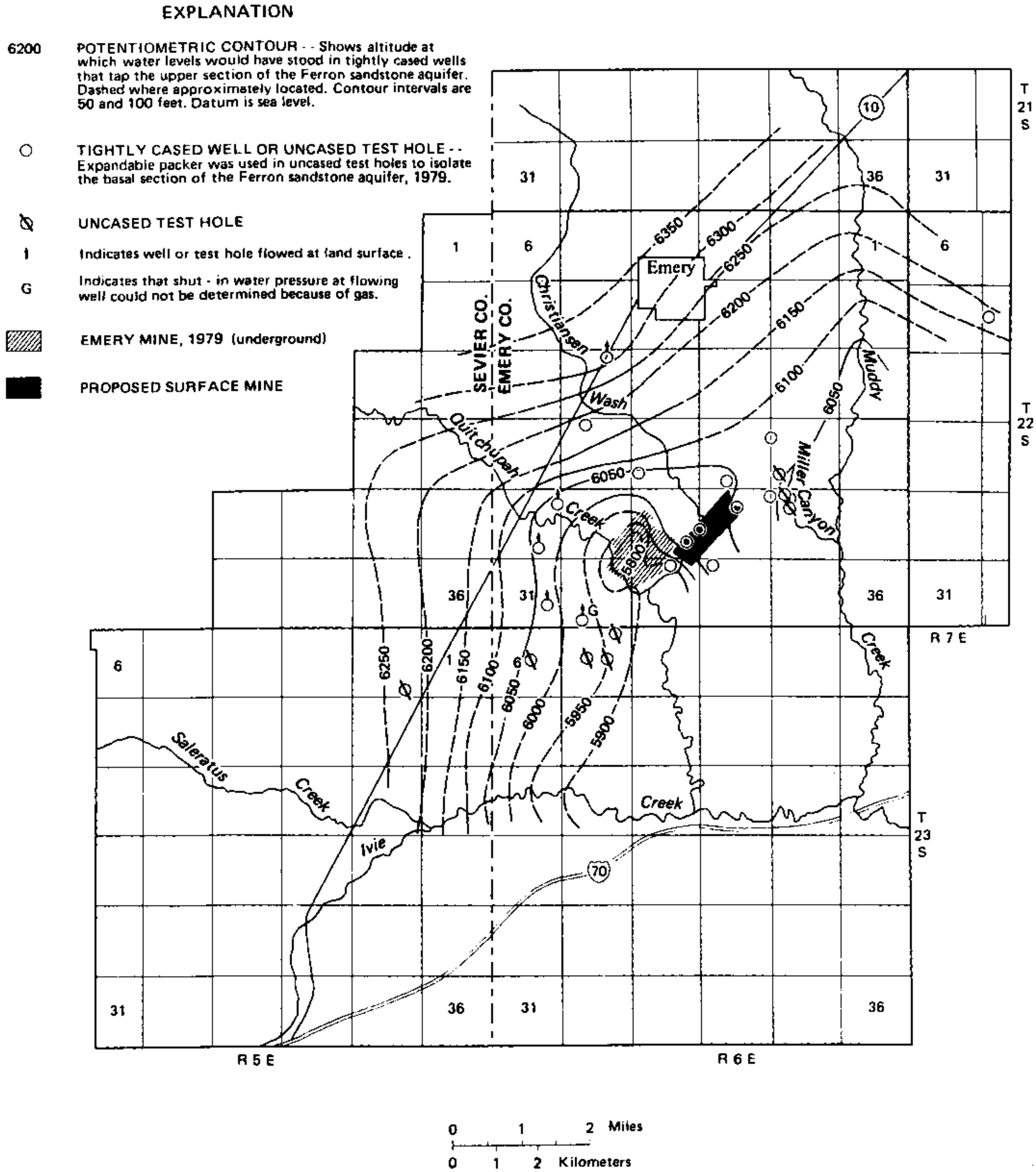

Figure 3.4-2.— Potentiometric surface of the upper section of the Ferron Sandstone aquifer.
(From Lines and Morrissey, 1983, fig. 9.)

3.5 WATER TABLE IN ROCKS OVERLYING THE FERRON

CONFIGURATION OF THE WATER TABLE DEFINED

In most areas, the water table in the Blue Gate and pediment gravels is lower than the potentiometric surface of the upper section of the Ferron Sandstone aquifer.

The approximate configuration of the water table (the level at which pressure is atmospheric) in rocks that overlie the Ferron Sandstone aquifer is shown in figure 3.5-1. During the summer of 1979, the water table in many areas was in the Blue Gate Member; but on the benches north of Quitchupah Creek, the water table was commonly in pediment gravels and alluvium.

Data to define the water table were available from 11 wells and test holes. Along perennial streams and irrigation canals and at springs that issue from the Blue Gate and pediment gravels, the water table was assumed to be at the altitude of the land surface. Along ephemeral streams, the water-table contours were drawn at an altitude below land surface. The water table was assumed to be within 50 feet of the land surface in areas of phreatophytes.

The water table in the Blue Gate and pediment gravels is lower than the potentiometric surface of the upper section of the Ferron Sandstone aquifer in most areas. This is not the condition, however, near the Emery Mine where the Ferron is being dewatered and where water from the Blue Gate leaks into the aquifer.

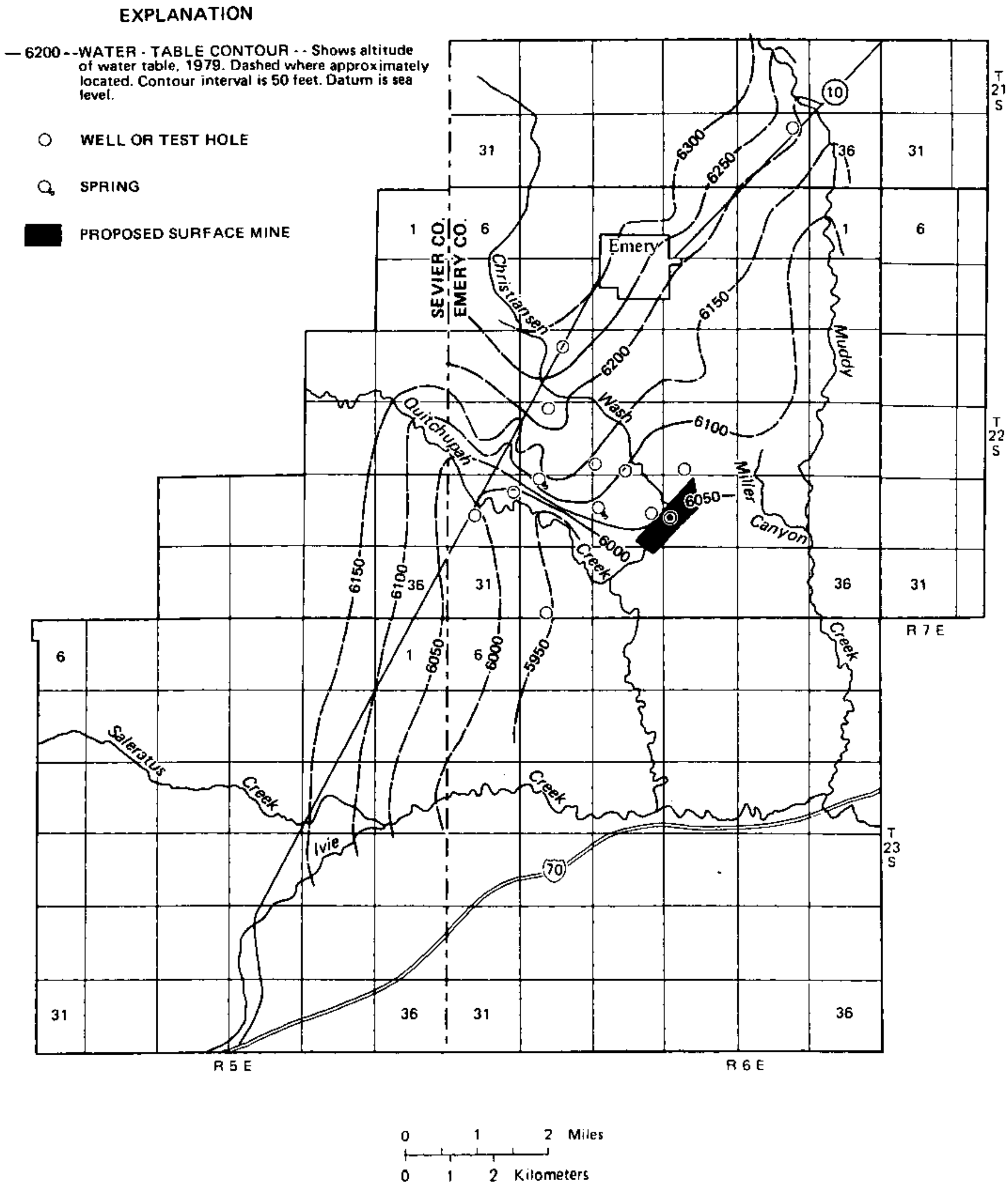

Figure 3.5-1.— Configuration of the water table in rocks that overlie the Ferron Sandstone aquifer.
(From Lines and Morrissey, 1983, fig. 10.)

3.0 THE GROUND-WATER SYSTEM

3.6 CHEMICAL QUALITY OF GROUND WATER

DISSOLVED-SOLIDS CONCENTRATIONS VARY MARKEDLY

Dewatering of the Emery Mine has changed water quality in the Ferron Sandstone aquifer.

Selected chemical analyses of ground water are listed in table 3.6-1. As shown in figures 3.6-1 and 3.6-2, dissolved-solids concentrations in the lower section of the Ferron Sandstone aquifer increase from the Paradise Valley-Joes Valley fault system toward the Ferron outcrop. Dissolved-solids concentrations also increase upward in the aquifer in most areas. Deterioration of water quality usually is due to increased concentrations of dissolved sodium and sulfate.

The configuration of lines of equal dissolved-solids concentration in figure 3.6-2 indicates that dewatering of the Emery Mine has improved water quality in the upper section of the Ferron between the mine and the fault system to the west. In this area, the increased movement of less saline water toward the mine from the west and from the lower part of the aquifer has more than offset any deterioration of water quality that may have been caused by downward leakage from the Blue Gate.

The largest observed dissolved-solids concentrations in the upper section of the Ferron east of the fault system were in an area near the proposed surface mine (fig. 3.6-2). Water in the Blue Gate Member, which contained about 20,000 mg/L of dissolved solids, was leaking into the Ferron in this area. The downward leakage of saline water from the Blue Gate was induced, at least in part, by dewatering of the Emery Mine.

Water quality in the Ferron deteriorates, at least in some areas, west of the Paradise Valley-Joes Valley fault system. This condition is consistent with the hypothesis that most of the water that recharges the Ferron from the west is transmitted along an extremely permeable zone created by the faulting.

Table 3.6-1— Selected chemical analysis of water from wells, test holes, springs, and the Emery Mine.

Water-bearing zone: Hub, Blue Gate Member of the Mancos Shale; Kmf, Ferron Sandstone Member of the Mancos Shale.

Method of Collection: A, air line used to lift water to surface; B, bailed; D, Sample collected while drilling with air; D6, sample recovered from drill-stem test; F, natural flow; p, pumped.

pH: Field determination except L, determined in laboratory.

Dissolved solids: Calculated from sum of constituents.

Specific conductance: Field determination except L, determined in laboratory; reported in micromhos per centimeter at 25˚ Celsius.

								Milligrams per Liter														
Location		Water-bearing zone	Interval sampled below land surface (feet)	Method of collection	Date of collection	Temperature (degree Celcius)	PH (units]	Dissolved Calcium (Ca)	Dissolved Magnesium (Mg)	Dissolved Sodium (Na)	Dissolved Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Dissolved Sulfate (SO_4)	Dissolved Chloride (Cl)	Dissolved Bromide (Br)	Dissolved Boron (B)	Dissolved Silica (SiO_2)	Hardness as $CaCO_3$	Noncarbonate Hardness as $CaCO_3$	Dissolved solids	Specific Conductance (micromhos at 25 ˚C)
T. 22S., R. 5E.																						
NE¼ SW¼ NE¼	sec. 23	Kmf	1,305-1,319	F	1-19-53	–	–	109	32	[1] 2,317	–	395	–	4,143	575	–	–	–	–	–	7,370	–
ditto.		Kmf	1,520-1,530	DS	1-28-53	–	–	222	62	[1] 2,077	–	855	–	3,465	707	–	–	–	–	–	6,954	–
T. 22S., R. 6E.																						
W¼ NE¼ NE¼	sec. 4	Kmf	1,586-1,614	F	2- 5-79	26.0	7.9	31	19	180	4.1	280	0	350	20	0.1	0.22	15	160	0	757	1,100
SW¼ NW¼ NE¼	sec. 17	Kmf	1,368-1,543	F	7-10-79	25.0	7.6L	29	19	200	4.4	300	–	300	32	.2	.23	16	150	0	749	1,150L
ditto.		Kmf	1,040-1,100	F	12-14-78	15.5	8.1	19	14	290	5.1	310	0	440	30	.2	.29	16	110	0	967	1,480
NW¼ SW¼ SW¼	sec. 21	Kmf	600- 725	A	11-30-78	10.5	9.0	19	16	460	4.4	570	5	590	31	.2	.61	12	110	0	1,420	2,100
SE¼ SE¼ SW¼	sec. 22	Kmf	100- 275	P	4-19-79	13.0	7.1	300	290	880	12.	640	0	3,200	120	.5	.62	19	1,900	1,400	5,140	6,100
NE¼ SE¼ SE¼	sec. 23	Kmf	Spring	F	4-04-78	10.0	7.5L	130	110	660	5.3	690	–	1,500	110	.5	.47	12	780	210	2,870	3,850L
NE¼ NW¼ NW¼	sec. 26	Kmf	At 29	B	5-31-78	12.5	–	510	370	240	8.3	6	–	3,000	45	.3	2.6	18	2,800	2,800	4,200	4,500
NW ¼ NW¼ NW¼	sec. 26	Kmf	40- 349	P	6-21-79	12.5	3.6L	110	930	940	10.	0	0	5,900	140	1.0	.77	36	4,100	4,100	8,070	10,700
NE¼ NW¼ SW¼	sec. 27	Kmf	75- 150	A	11-17-78	8.5	7.4L	140	220	760	48.	330	–	2,500	20	.5	.43	21	1,300	980	3,870	5,000
ditto.		Kmb	51- 71	B	5-31-79	11.0	7.9L	170	1,100	4,000	46.	300	–	12,000	230	.8	1.1	6.9	5,000	4,700	17,700	20,000
NE¼ SW¼ NW¼	sec. 28	Kmf	In Mine	F	3-29-79	13.0	8.7	9.3	9.2	380	2.6	590	0	390	28	.2	.59	12	61	0	1,120	1,620
NE¼ NW¼ SW¼	sec. 28	Kmf	In Mine	F	9-01-78	13.5	8.4	24	29	420	2.6	[2] 630	–	520	28	.3	.58	13	180	0	1,350	2,040L
SW¼ NE¼ NE¼	sec. 30	Kmf	838- 884	F	10-15-79	19.0	8.0	12	6.9	220	4.4	[2] 400	0	180	16	.1	.35	14	58	0	652	1,100
SE¼ NW¼ NW¼	sec. 34	Kmf	At 160	D	12-12-78	10.5	8.9	10	6.3	260	6.3	430	–	230	23	.1	.36	11	51	0	759	1,100
		Kmf	273- 360	A	12-04-78	9.0	9.1	14	7.4	300	5.2	700	17	140	21	.2	.47	3.9	65	0	854	
T. 23S., R. 6E.																						
SW¼ SW¼ NE¼	sec. 6	Kmf	At 385	D	11-21-78	12.5	8.2	35	19	370	4.1	280	0	660	49	.4	.30	15	170	0	1,290	1,980
ditto.		Kmf	665- 720	A	11-28-78	13.5	8.9	13	4.3	290	3.2	370	13	330	30	.2	.35	11	50	0	877	1,400
NE¼ NW¼ SE¼	sec. 17	Kmf	Spring	F	11-08-78	13.0	7.4 L	210	190	470	8.1	360	–	1,800	150	.6	.56	16	1,300	1,000	3,020	3,720L
NW¼ SE¼ SE¼	sec. 18	Kmf	160- 484	F	10-26-78	17.0	7.8	34	18	170	4.2	280	0	290	16	.2	.19	15	160	0	686	980
NW¼ NW¼ NW¼	sec. 32	Kmf	225- 280	P	9-20-78	13.5	8.7L	6.0	2.1	370	1.8	420	–	450	16	.4	.33	8.1	24	0	1,060	1,650

[1] Sodium plus potassium

[2] Estimated from total laboratory alkalinity

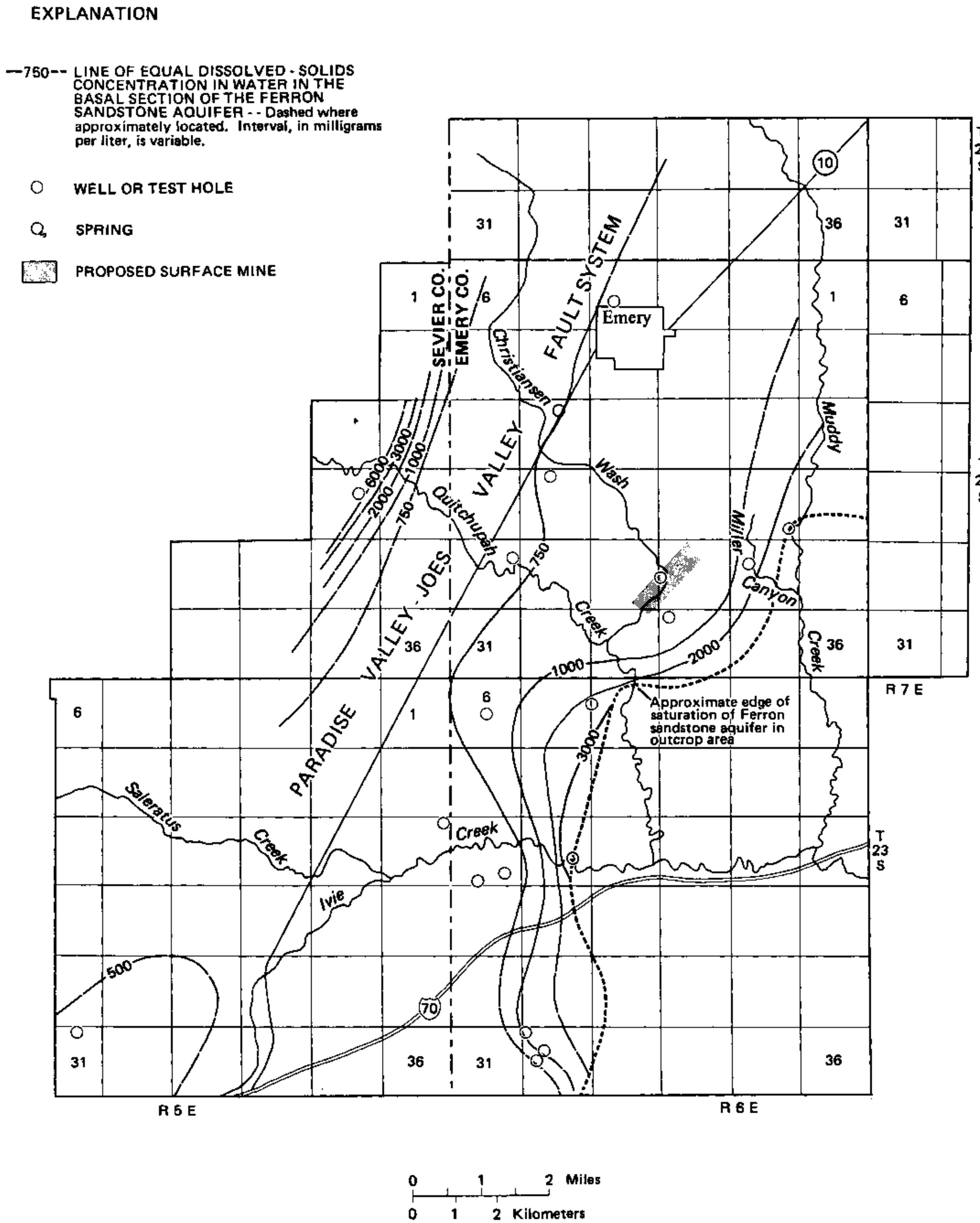

Figure 3.6-1.— Concentration of dissolved solids in water in the basal section of the Ferron Sandstone aquifer.
(From Lines and Morrissey, 1983, fig. 14.)

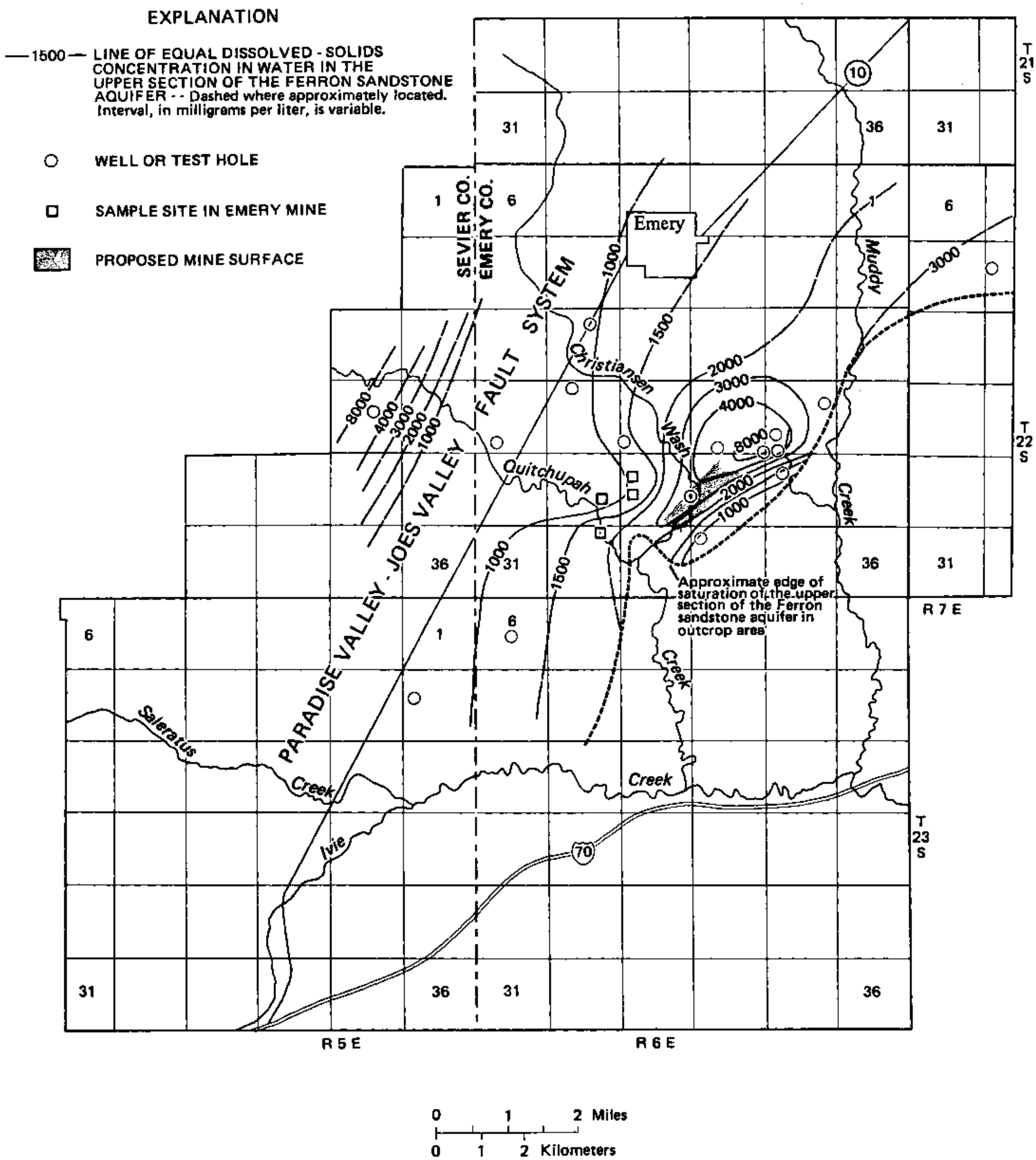

Figure 3.6-2.— Concentration of dissolved solids in water in the upper section of the Ferron Sandstone aquifer.
(From Lines and Morrissey, 1983, fig. 15.)

4.0 PROBABLE HYDROLOGIC CONSEQUENCES

4.1 UNDERGROUND MINING

PATTERN OF GROUND-WATER FLOW CHANGED BY MINE DEWATERING

Water levels in wells have declined due to dewatering of the Emery Mine.

Dewatering of the Emery Mine has changed the pattern of ground-water flow near the mine, and part of the upper section of the Ferron Sandstone aquifer has been dewatered. Changes in the flow pattern near the mine are illustrated in figure 4.1-1. Prior to mining, the vertical component of flow was upward from the Ferron into the Blue Gate Member. As mining progressed, ground-water flow was directed toward the mine workings, and much of the aquifer and other rocks above the mined coal bed were dewatered. The steady-state pattern of flow shown in figure 4.1-1 probably would not develop unless mining ceased and dewatering of the mine continued for several years.

Discharge from the mine averaged 0.7 ft^3/s during 1979, and the discharge will probably increase as the mine progresses farther downdip and into areas of larger aquifer transmissivity.

Water levels in four representative wells completed in the Ferron Sandstone aquifer in the Emery coal field are shown in figure 4.1-2. Water-level declines in the wells are due to manmade withdrawals of water from the aquifer, mainly dewatering of the Emery Mine. The two hydrographs (fig. 4.1-2) that have the smallest and greatest water-level declines are for wells in the NW¼NW¼SW¼ sec. 27, T. 22 S., R. 6 E. The water level in the well completed in the Blue Gate and most of the Ferron Sandstone aquifer has changed very little in comparison to the water level in the well completed in the upper section of the Ferron. The different water-level responses indicate the importance of constructing observation wells completed in only a small interval of an aquifer, particularly near dewatered mine shafts where head differences with depth can be great.

As discussed earlier, dewatering of the Emery Mine has improved water quality in the upper section of the aquifer in some areas, particularly west of the mine. However, water quality in the upper section of the Ferron has deteriorated northeast of the mine as a result of induced leakage of saline water from the Blue Gate.

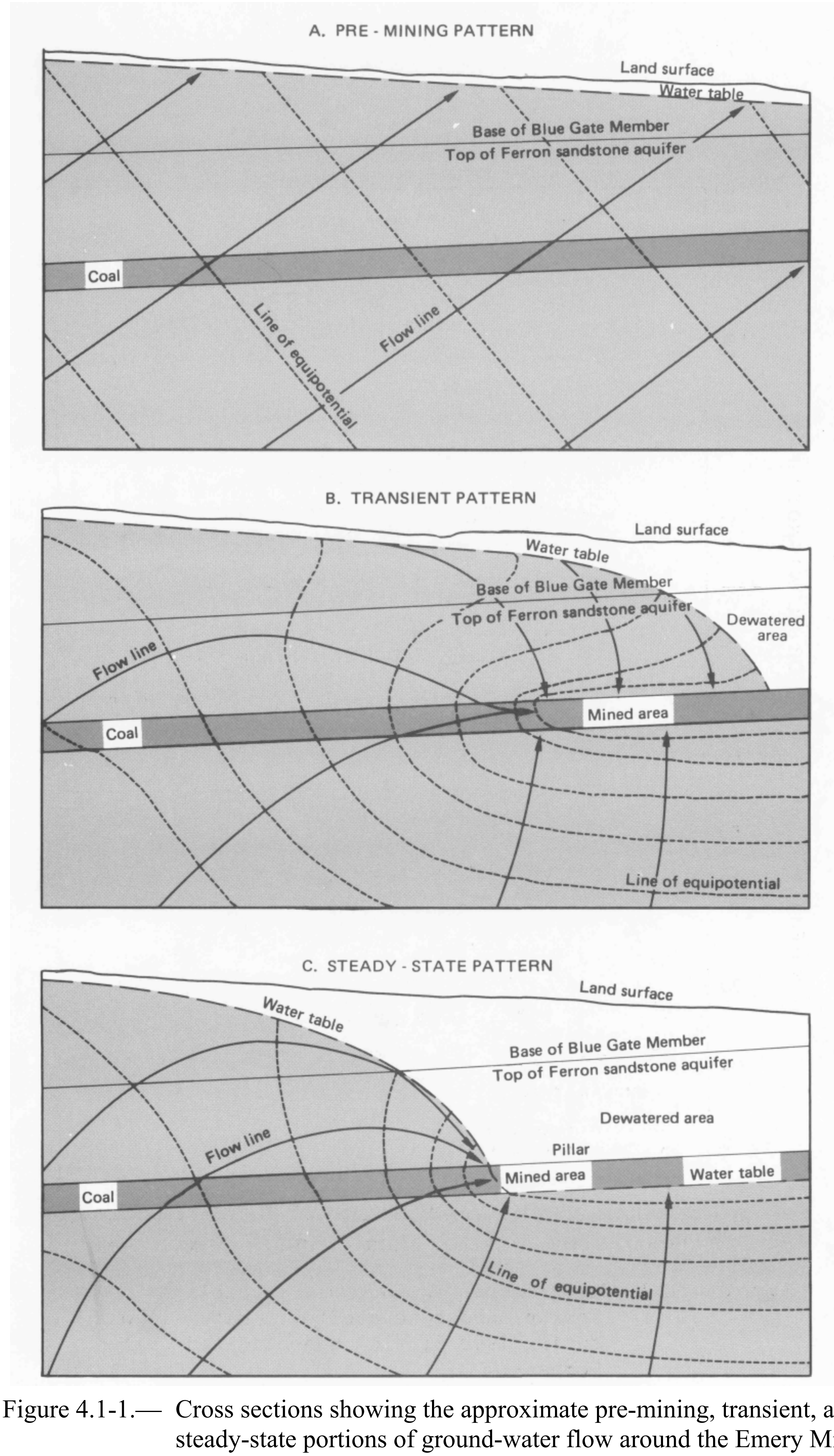

Figure 4.1-1.— Cross sections showing the approximate pre-mining, transient, and steady-state portions of ground-water flow around the Emery Mine.

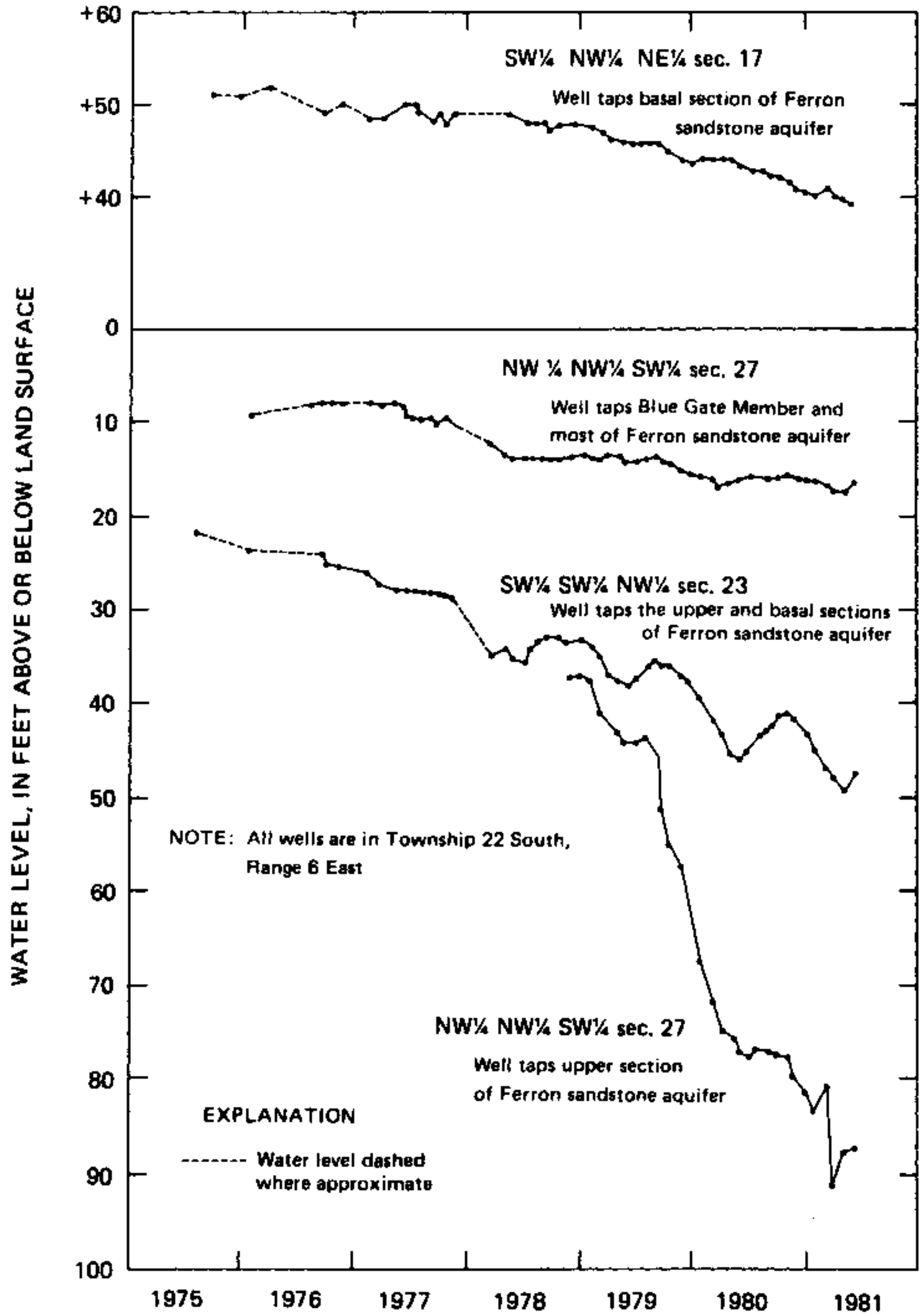

Figure 4.1-2.— Water levels in four wells completed in the Ferron Sandstone aquifer. (Water levels during 1980-81 from Consolidated Coal Company.)

4.0 PROBABLE HYDROLOGIC CONSEQUENCES

4.2 PROPOSED SURFACE MINING

HYDROLOGIC EFFECTS OF SURFACE MINING CAN BE PREDICTED

Discharge from the mine is predicted to average 0.3 ft^3/s; in the upper section of the Ferron Sandstone aquifer, drawdowns greater than 5 feet would extend about 2.5 miles from the mine after 15 years.

A three-dimensional digital-computer model was used to simulate ground-water flow in the Ferron Sandstone aquifer and to predict the effects of dewatering the proposed surface mine on potentiometric surfaces and the base flow of streams (8). Although predictions made with the model are considered to be semiquantitative, the model provides the most realistic method available to analyze the effects of mine dewatering on the aquifer.

Discharge from the surface mine is predicted to average about 0.3 ft^3/s during the proposed 15 years of operation. Water discharged from the surface mine would be balanced by a decrease in storage in the Ferron Sandstone aquifer, by a decrease in water entering the underground Emery Mine, by a decrease in natural leakage from the aquifer, and by an increase in leakage from the Blue Gate Member.

The predicted drawdown of the potentiometric surface of the upper section of the Ferron Sandstone aquifer (the section in which surface mining is proposed) after 15 years of mine dewatering is shown in figure 4.2-1. Other sections of the aquifer also would be affected, but drawdowns would not be as great.

Model calculations indicate that leakage from the Blue Gate into the Ferron would increase by about 0.05 ft^3/s. Practically all (98 percent) of the increased leakage would occur within the area of drawdown greater than 5 feet shown in figure 4.2-1. Dewatering of the surface mine may further deteriorate water quality in the upper section of the Ferron in the area between the mine and the head of Miller Canyon. However, water quality in the upper section of the Ferron may improve in other areas as it did near the underground mine, particularly in the area west of the surface mine.

Modeling results indicate that dewatering of the surface mine would not affect the base flow of streams. If water from the mine were discharged into Christiansen Wash, however, streamflow would increase accordingly. The predicted mine discharge of 0.3 ft^3/s would almost be equal to the minimum observed flow of Christiansen Wash during 1979.

Water entering the surface mine would be mainly from the Ferron Sandstone aquifer, which contains 1,000 to 8,000 mg/L of dissolved solids. Some water from the Blue Gate Member, which contains about 20,000 mg/L of dissolved solids, also will enter the mine. Chemical quality of the mine water, therefore, would vary with time and probably would have dissolved-solids concentrations within a range of 2,000 to 10,000 mg/L. The dissolved-solids

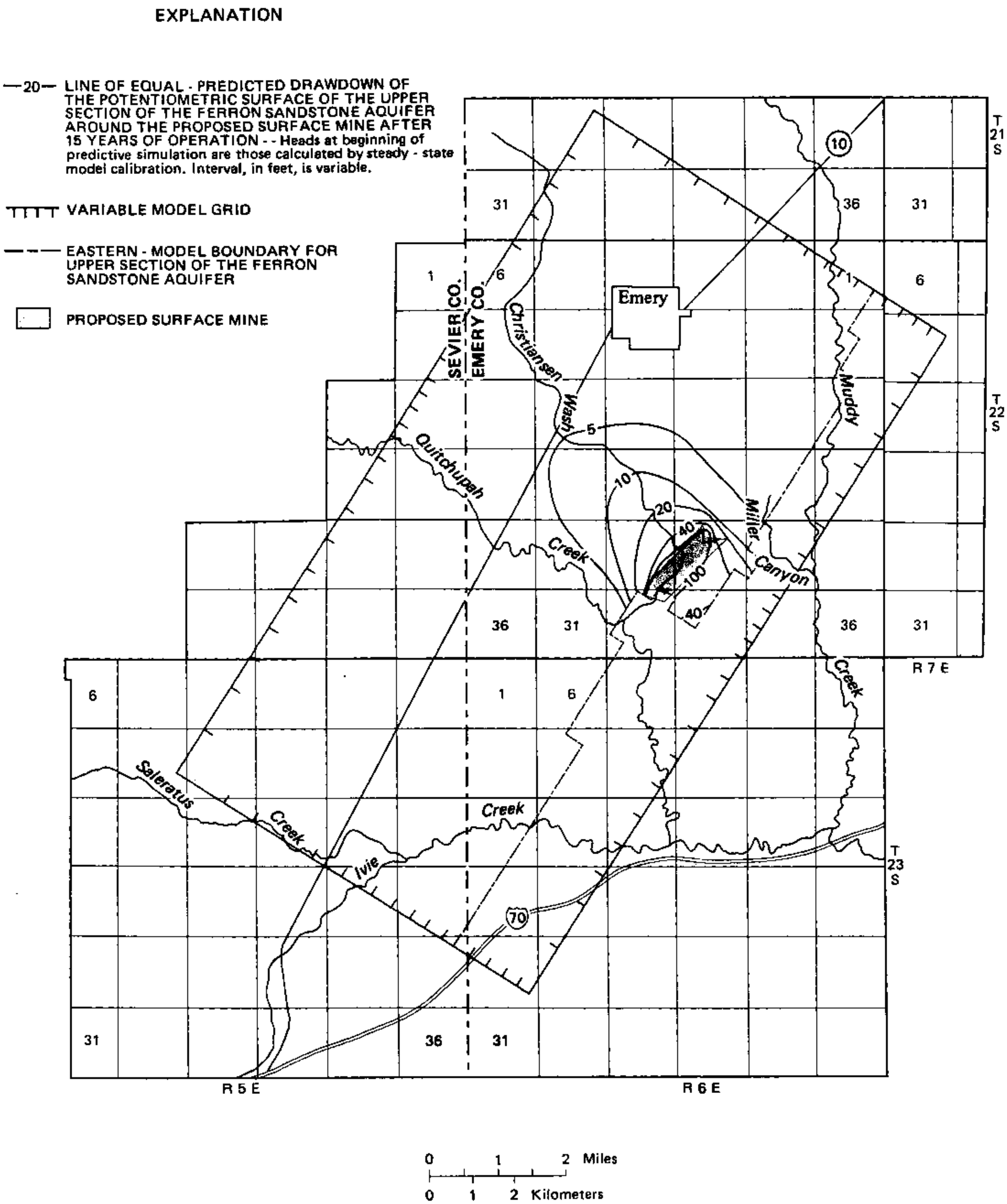

Figure 4.2-1.— Variable grid used in the three-dimensional digital-computer drawdown of the potentiometric surface of the upper section of the Ferron Sandstone aquifer around the proposed surface mine after 15 years of operation. (From Lines and Morrissey, 1983, fig. 20.)

concentrations of 12 samples obtained monthly from Christiansen Wash downstream from the proposed surface mine during the 1979 water year ranged from 582 to 4,470 mg/L (5). Thus, at least during some periods, the dissolved-solids concentration of water in Christiansen Wash would be increased if mine water were discharged into the stream.

5.0 GROUND-WATER MONITORING

NETWORK OF OBSERVATION WELLS NEEDED

The observation wells are needed to monitor changes in potentiometric surfaces and changes in water quality caused by mine dewatering.

A network of observation wells would be needed near the underground Emery Mine and the proposed surface mine to monitor changes in potentiometric surfaces and water quality in the Ferron Sandstone aquifer. Observation wells would be constructed so that each well is completed in a selected part of the aquifer. The wells would be grouped in clusters of three: one well would be completed in the Blue Gate Member; one, the upper section of the Ferron; and, one, the lower section of the Ferron.

Five or six clusters of observation wells in which water levels are measured monthly probably would be adequate to monitor changes in potentiometric surfaces. In addition, wells completed in the upper section of the Ferron (the section that will be mined) would need to be pumped annually to obtain samples for chemical analyses and to detect possible changes in water quality. One possible network of observation wells is shown in figure 5.0-1.

The quantity of water discharge from the mines would need to be continuously monitored. Temperature, specific conductance, and pH of the mine-discharge water would be monitored daily and samples collected for chemical analysis at least monthly.

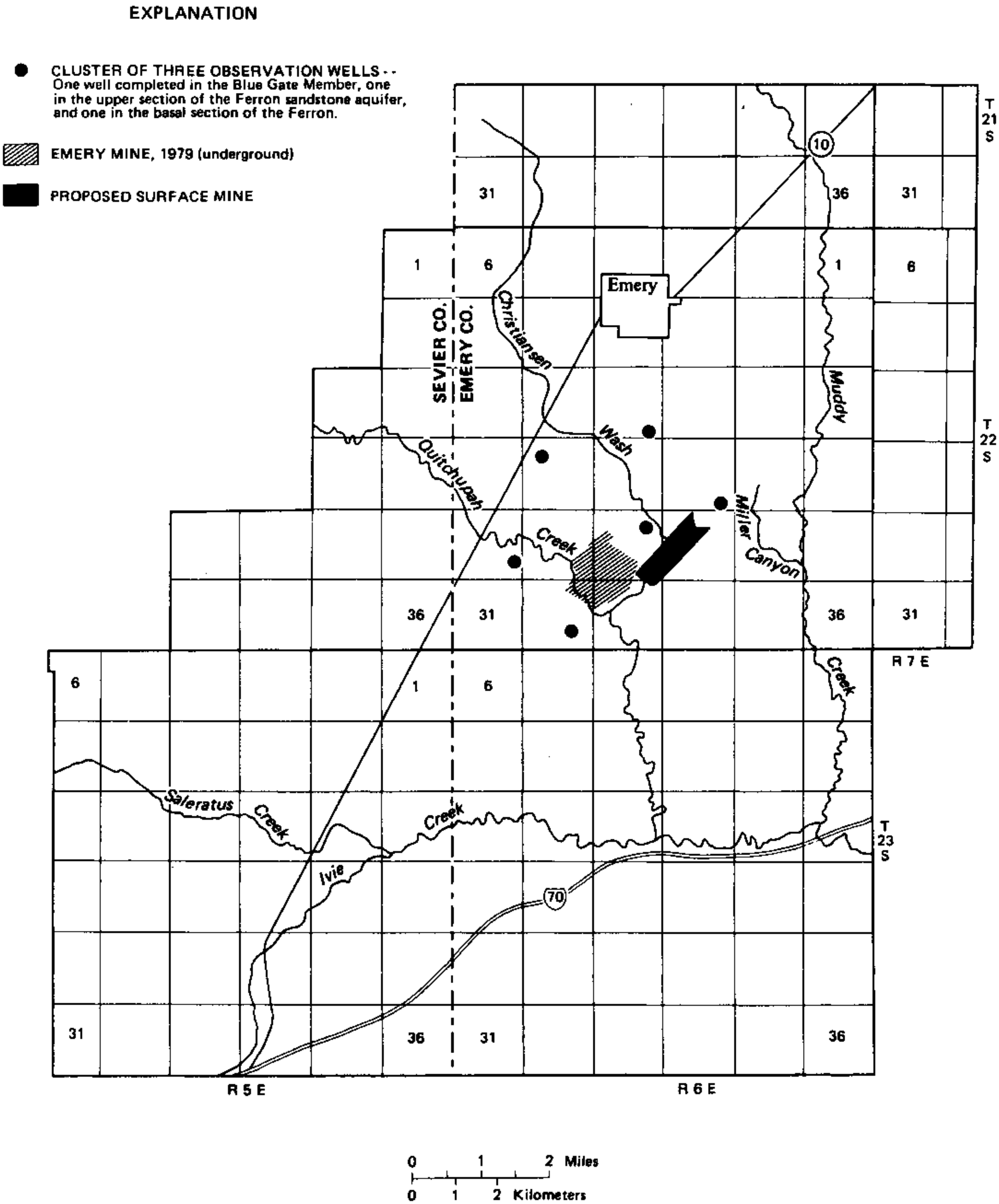

Figure 5.0-1.— A hypothetical network of observation wells used to monitor water levels and water quality near the Emery mine and the proposed surface mine.

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