PREDICTED EFFECTS OF UNDERGROUND MINE FLOODING AT TRACT C-b IN PICEANCE BASIN, NORTHWESTERN COLORADO

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This report uses inch-pound units for all numerical data; these units can be converted to metric (International System) units with the following multiplication factors:

Multiply inch-pound unit	*By*	*To obtain metric unit*
foot (ft)	0.3048	meter
foot squared per day (ft^2/d)	9.290×10^{-5}	meter squared per day
cubic foot per day (ft^3/d)	2.8317×10^{-5}	cubic meter per day
cubic foot per second	2.8317×10^{-5}	cubic meter per second
gallon per minute (gal/min)	0.06309	liter per second
square mile (mi^2)	2.590	square kilometer

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level of 1929."

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ABSTRACT

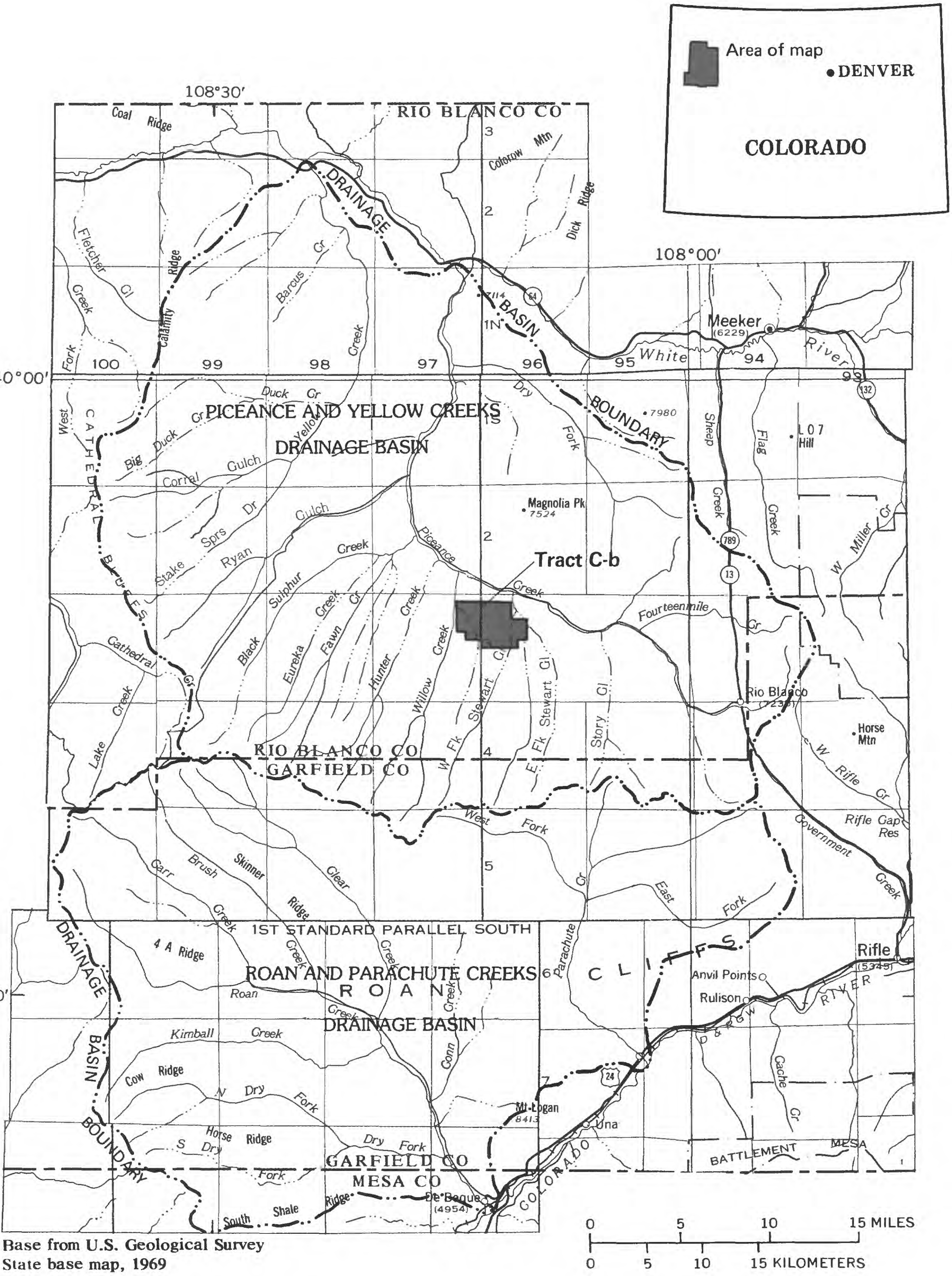
Tract C-b is a Federal oil-shale lease tract in the Piceance basin in northwestern Colorado. Pumping of mine shafts to drain mine workings and water injection in a well near the shafts have occurred at Tract C-b from 1981 to the present (1987). The operators have proposed to stop the pumping to drain the mine and to permit flooding of the mine workings. The U.S. Geological Survey has estimated the hydrologic effects of flooding of the mine.

Simulation modeling of mine pumpage and flooding at Tract C-b indicate that recovery of the hydrologic system from the major effects of pumping will occur in a few years. After this period of transient recovery, a steady-state flow system will occur and water from the upper aquifers will drain slowly into the lower aquifers through three mine shafts. Though less likely, degradation of water quality in the upper aquifers possibly may result from upward migration of relatively saline water from the lower aquifers through the shafts. This migration could be caused by convection in the shafts in response to the natural thermal gradient, natural diffusion processes, construction of pumped or injection wells nearby, or decreased natural recharge.

INTRODUCTION

Tract C-b is a Federal oil-shale lease tract in the northern part of Piceance basin in northwestern Colorado (fig. 1). Three shafts and five connecting tunnels were constructed in preparation for the mining of oil shale and associated minerals. The shafts were pumped at variable rates from 1981 to the present (1987) to drain ground water from zones planned for mining or in-situ processing of oil shale. Water was injected in a well near the tract.

The operators of Tract C-b (Cathedral Bluffs Shale Oil Co.) seek permission from the U.S. Bureau of Land Management to stop pumping water from the shafts and allow the mine to flood; plugging of shafts and tunnels is not planned. The purpose of this report is to estimate the effects of ceasing to pump water from the mine shafts and abandoning the unplugged mine shafts and tunnels on the hydrologic system. Specifically, the possibility of mixing water from the lower and upper aquifers is addressed because water in the lower aquifers generally has diminished quality compared to water in the upper aquifers. This report was prepared in cooperation with Rio Blanco County in northwestern Colorado.



Base from U.S. Geological Survey
State base map, 1969

Figure 1.--Piceance basin showing location of Tract C-b.

HYDROGEOLOGIC SETTING

The Piceance basin, which encompasses an area of about 1,600 mi^2, is a structural basin that is drained by four principal drainage systems: Piceance, Yellow, Roan, and Parachute Creeks. The basin contains large resources of oil shale and sodium minerals within the Green River and Uinta Formations of Tertiary age. Fractured shale and sandstone aquifers in these formations, as well as alluvial aquifers, are the subject of this analysis. The bedrock aquifer system consists of lower aquifers that are separated from upper aquifers by the Mahogany Zone, a confining layer. The alluvial aquifers occur along major streams in the basin. The permeability of all aquifers varies considerably. Average thickness of the bedrock and alluvial aquifer system is about 1,750 ft.

In the northern part of the Piceance basin, the bedrock aquifers are recharged by snowmelt and rainfall (fig. 2). Recharged water moves through the upper and lower aquifers and discharges into the valley-fill alluvium or as springs in the valleys of Piceance and Yellow Creeks and their tributaries. Water recharged to or discharged from the lower aquifers is transmitted through the Mahogany zone, even though it is a confining layer.

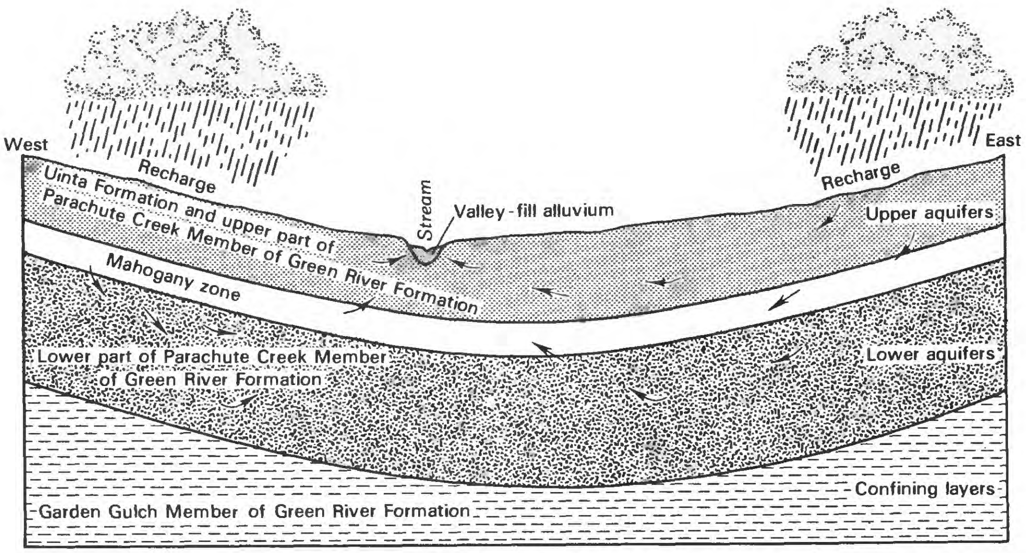


Figure 2.--Ground-water flow system in the northern part of Piceance basin.

MINE SHAFTS

In 1979, the Cathedral Bluffs Shale Oil Co. began excavating three shafts on Tract C-b in Piceance basin, Colorado. The production (P) and service (S) shafts are located in sec. 12, T. 3 S., R. 97 W. (fig. 3). The P shaft was constructed to withdraw ore; the S shaft was constructed to lower miners and equipment. The P and S shafts penetrate the upper aquifers, and they bottom in the R-5 zone (fig. 4). The P and S shafts are 250 ft apart and are connected by five horizontal tunnels at various depths. The ventilation and escape (VE) shaft is located in sec. 1, T. 3 S., R. 97 W., and it penetrates the upper aquifers and bottoms in the R-6 zone. The VE shaft was constructed to ventilate the mine and to provide escape for miners in an emergency. The shafts were pumped to drain the mine, and the water was initially discharged to Piceance Creek. All shafts have leaking concrete liners that drain the aquifers at numerous depths. Shaft diameters and pumping periods are:

Shaft	Diameter (feet)	Pumping period
P	29	1979-87
S	34	1979-87
VE	15	1979-81

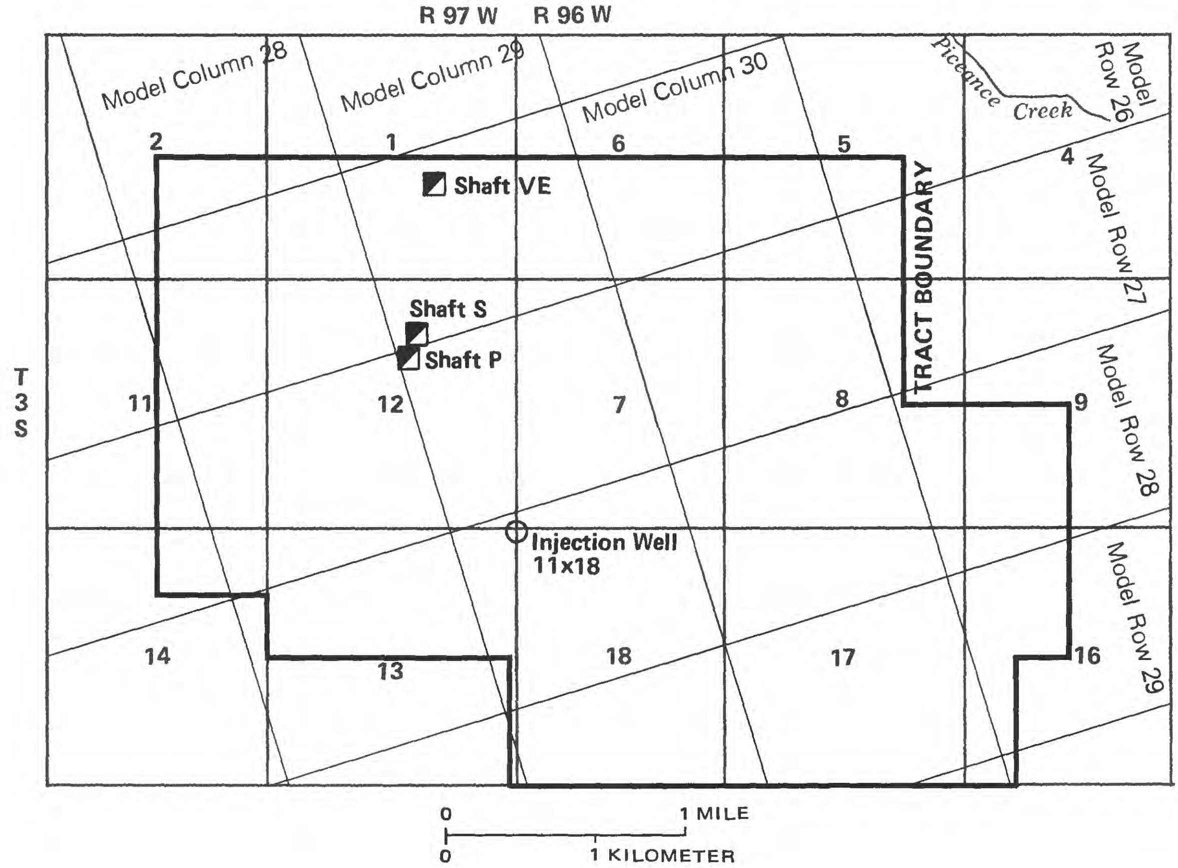


Figure 3.--Location of shafts and injection well and part of model grid.

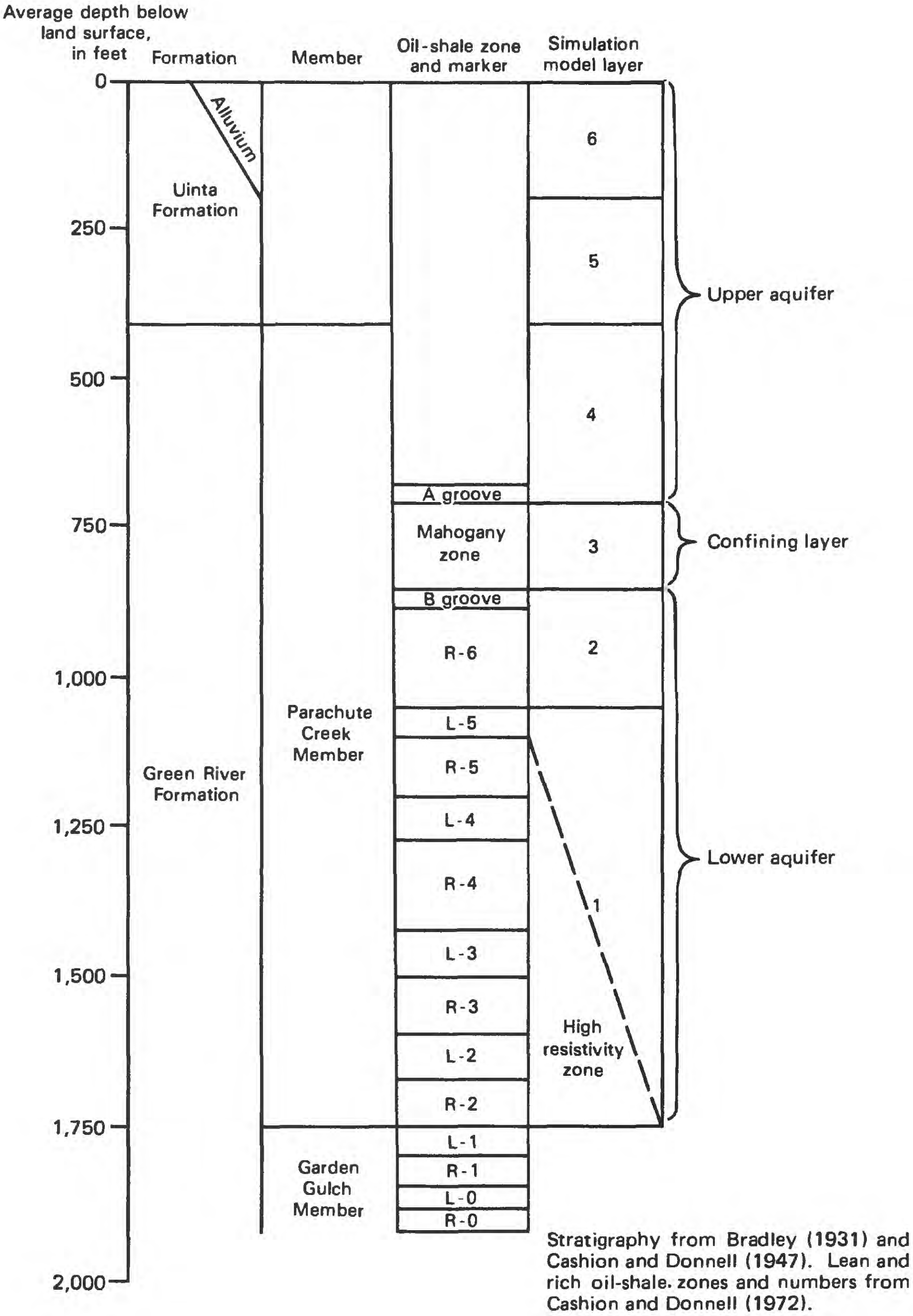


Figure 4.--Generalized correlation of stratigraphic, oil-shale, and simulation-model layers, Piceance basin.

During 1981-82, water pumped from the shafts was injected into well 11X18 (fig. 3). The injection was done to avoid discharging water that has a large concentration of fluoride into the river.

The concentration of the trace element fluoride ranges from 10 to 30 mg/L (milligrams per liter) in the lower aquifers, but it is less than 10 mg/L in the upper part of the upper aquifers (Robson and Saulnier, 1981). The dissolved-solids concentration in the lower aquifers commonly is about 2,000 mg/L; in the upper aquifers the concentration generally is less than 1,000 mg/L.

REGIONAL SIMULATION MODELING OF MINE PUMPING AND FLOODING

The regional effects of pumping the mine shafts to drain the mine workings and the cessation of pumping to allow the mine workings and shafts to flood were analyzed using a simulation model described by Taylor (1986). This model incorporates six layers of 1,840 nodes each. The lower aquifers are simulated as layers 1 and 2; the Mahogany zone, a confining layer, is represented as layer 3. The upper aquifers and valley-fill alluvium are simulated as layers 4, 5, and 6 (fig. 4). Streams and springs are simulated as head-dependent discharge sites. This model was designed to simulate the regional flow system in the basin; it was not designed to simulate in detail the local results of pumping such as mine drainage at Tract C-b. Nevertheless, the model was used to predict, in a general sense, the effects of pumping and recovery at locations distant from the tract.

Historical pumpage and injection at Tract C-b were combined into net pumpage for 1981-86 (fig. 5). The net pumpage was simulated at model column 29, model row 27, layer 1 (fig. 3). The net stress was simulated at this single node to avoid simulating stresses too close to, or too distant from Piceance Creek in the coarse grid of the model. In addition, 50 years of recovery were simulated, assuming that pumping ceased at the end of 1986. Predicted effects of pumping are shown in figures 6 through 9. The model predicted that the effects on streams, springs, and water in storage would diminish during the last 5 years of the pumping period because of decreased net pumping rates. It also predicted that the decline and recovery of water levels due to pumping would be rapid and widespread in the artesian basin.

LOCAL HYDROLOGIC EFFECTS OF SHAFTS AND TUNNELS

The local effects of nonsteady flow to multiaquifer wells or shafts was analyzed by Papadopulos (1966). However, the local nonsteady effects of flow after mine flooding were not considered in this analysis because the simulation analysis predicted the nonsteady flow period would be short, and because it was assumed that the long-term effects of mixing of water from the upper and lower aquifers would be more severe than the short-term nonsteady effects.

After the hydrologic system recovers from the effects of pumping, an equilibrium will be reached in the system that is different from the equilibrium prior to pumping, because the shafts connect the upper and lower aquifers. This new equilibrium was analyzed by estimating the water level in the shafts that would be achieved when the upper and lower aquifers are connected and by calculating the flow in the shafts at that water level.

At the P and S shafts, the original difference in water levels between the upper and lower aquifers was about 65 feet:

Water level in upper aquifers	6,540 feet
Water level in lower aquifers	6,475 feet
Difference in water levels	65 feet

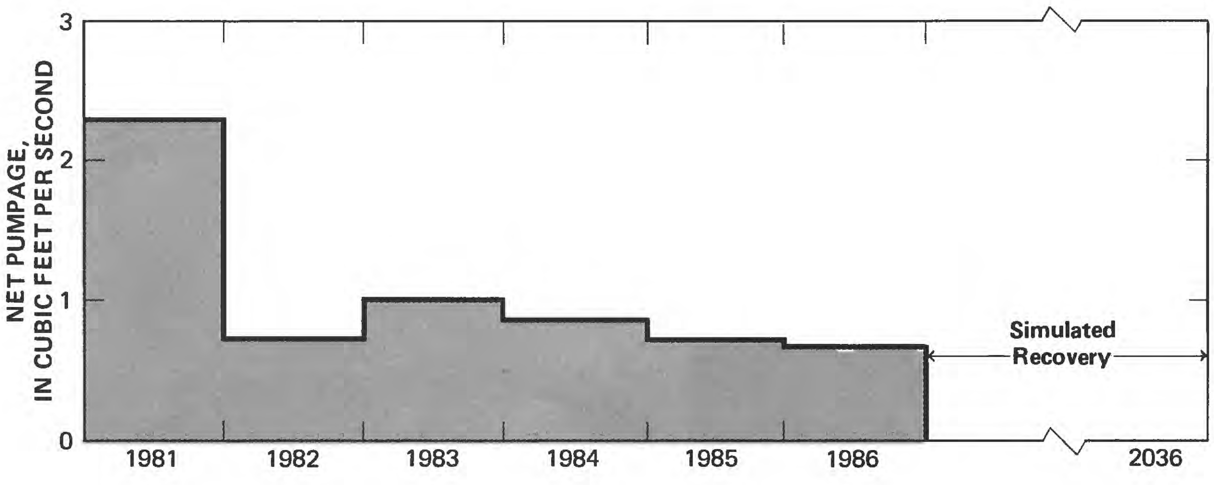


Figure 5.--Net pumpage at Tract C-b, 1981-86.

These water levels were estimated from potentiometric-surface maps prepared using hydraulic-head data from wells before pumpage from the shafts and injection into well 11X18 had begun (Kent Glover, U.S. Geological Survey, written commun., 1987). The water levels indicated a downward hydraulic gradient and associated downward movement of ground water under natural conditions. Water levels reported by J.H. Birman (Geothermal Surveys, Inc., written commun., 1987) are several hundred feet lower and seem to have been affected by pumpage during shaft construction.

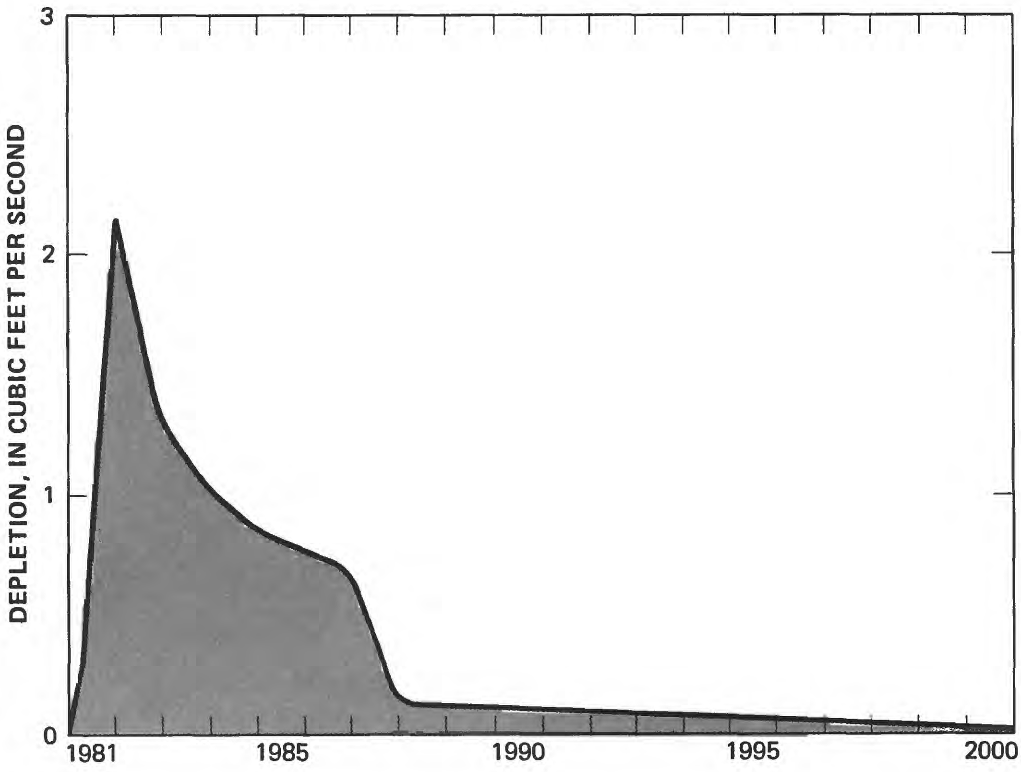


Figure 6.--Simulated depletion of streamflow and spring discharge, 1981-2000.

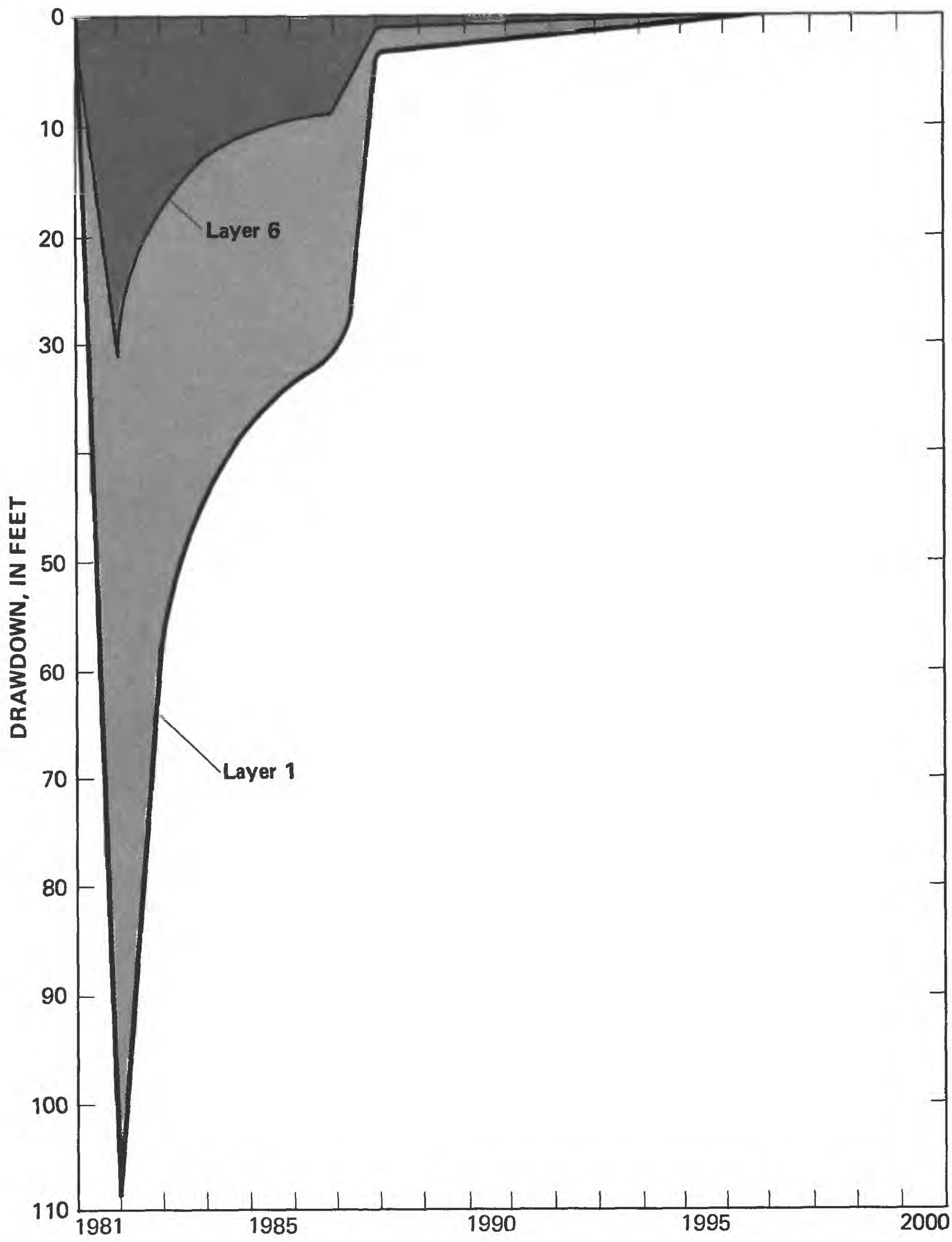


Figure 7.--Simulated drawdown at model row 28, model column 30, in model layers 1 and 6, 1981-2000.

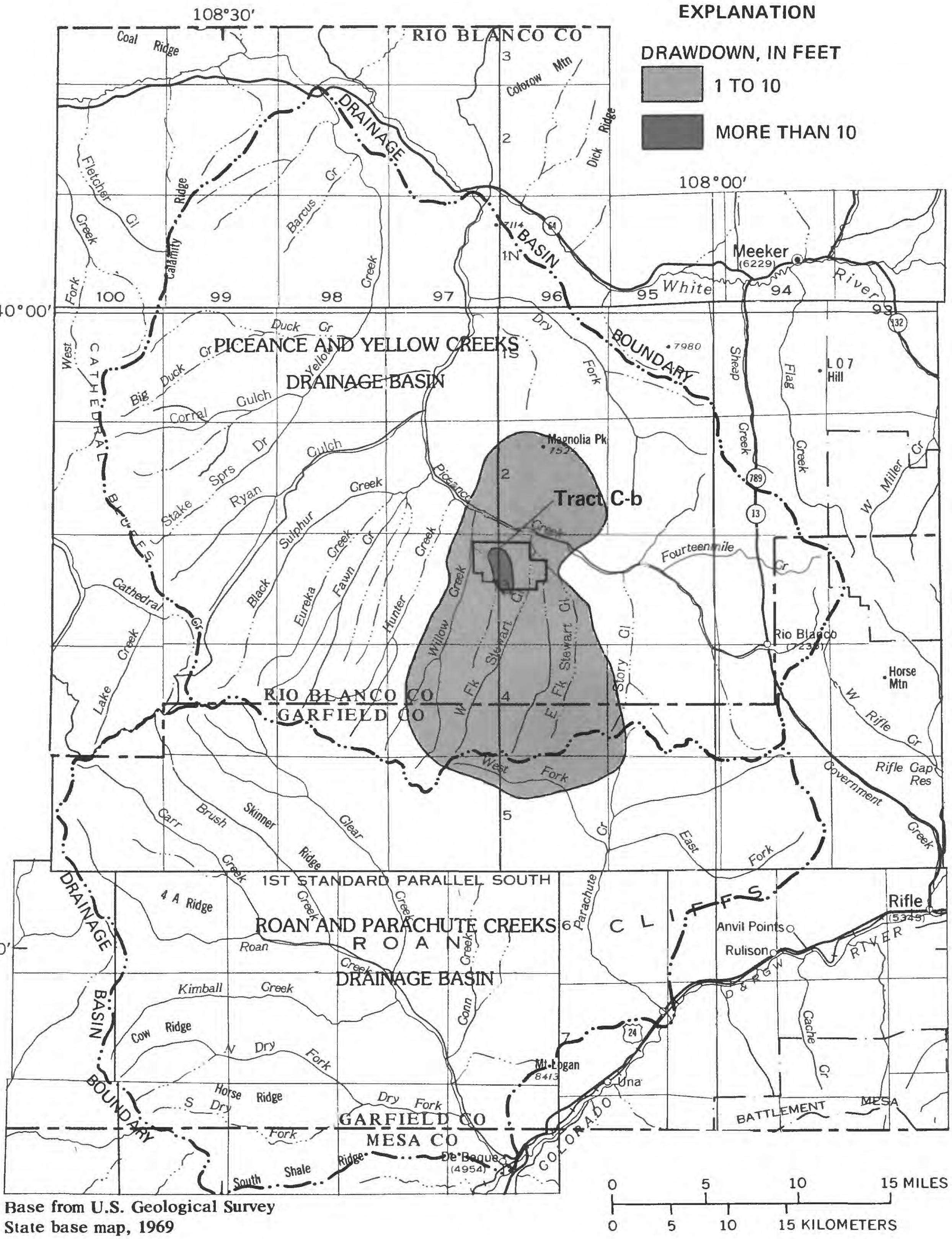
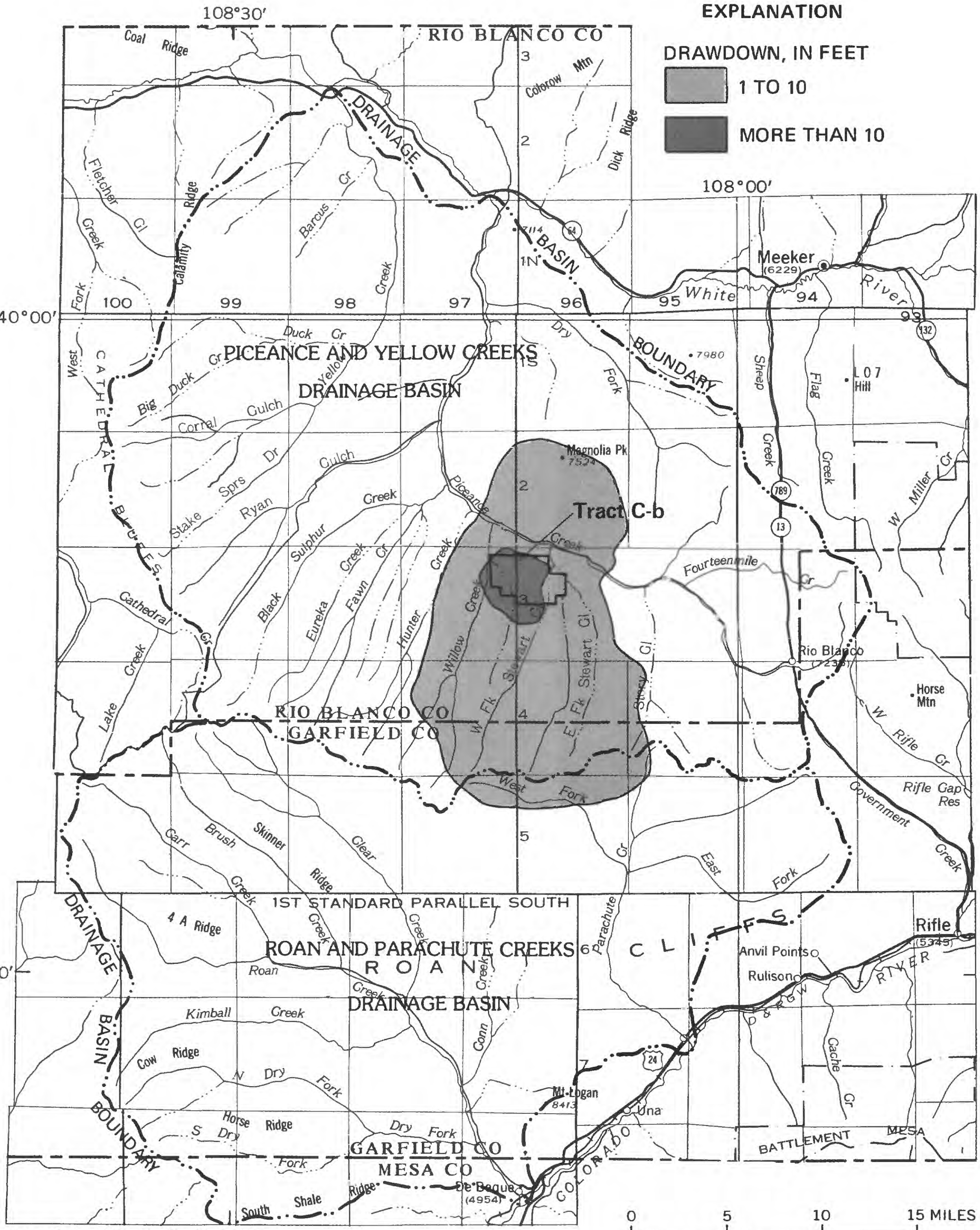


Figure 8.--Simulated drawdown in model layer 6 at the end of 1986.



Base from U.S. Geological Survey
State base map, 1969

Figure 9.--Simulated drawdown in model layer 1 at the end of 1986.

After the effects of pumpage and injection are over, the potentiometric levels in the upper and lower aquifers will equilibrate near the shafts because the shafts penetrate both aquifers. The sum of hydraulic-head changes will equal 65 ft, and the ratio of hydraulic-head changes in each aquifer will be inversely proportional to the transmissivity ratio:

$$\Delta h_u / \Delta h_\ell = T_\ell / T_u \ , \qquad (1)$$

where

Δh_u = hydraulic-head change in shaft for upper aquifers, in feet;

Δh_ℓ = hydraulic-head change in shaft for lower aquifers, in feet;

T_u = transmissivity of upper aquifers, in feet squared per day; and

T_ℓ = transmissivity of lower aquifers, in feet squared per day.

The sum of hydraulic-head changes will equal the original difference in water levels in the two aquifers:

$$\Delta h_u + \Delta h_\ell = 65 \text{ ft.}$$

Estimated values of transmissivity are:

T_u = 500 ft^2/d; and

T_ℓ = 100 ft^2/d.

Therefore,

T_ℓ/T_u = 0.2;

Δh_u = 11 ft; and

Δh_ℓ = 54 ft.

The equilibrium water level in the shafts will induce flow downward from the upper aquifers to the lower aquifers through the shafts. Therefore, water that has relatively small dissolved-solids concentration in the upper aquifers will mix with water in the lower aquifers, where the dissolved-solids concentration is relatively large. The flow is constrained by the equilibrium water level in the shafts and the relatively small transmissivity of the lower aquifers. In addition, the hydraulic-head changes induced near the shaft will decrease the normal downward flow through the Mahogany zone (fig. 10). Estimated flow through the shafts and the effects of connecting tunnels is calculated below.

The relation between discharge and constant drawdown for a well or shaft was analyzed by Jacob and Lohman (1952). The discharge, using consistent units, is given by:

$$Q = 2\Pi T s_w G(\alpha) \ , \qquad (2)$$

where

Q = well discharge;

T = transmissivity;

s_w = drawdown in well;

$G(\alpha)$ = mathematical function;

$\alpha = Tt/Sr_w^2$;

t = elapsed time since the discharge began;

S = coefficient of storage; and

r_w = well radius.

Assume the following quantities:

T = 240 ft^2/d (transmissivity of layers 5 and 6 of the upper aquifers--those layers most affected by the drawdown);

s_w = 11 ft;

t = 1,000 days (assumed);

S = 0.05 (estimated); and

r_w = 17 ft (service shaft).

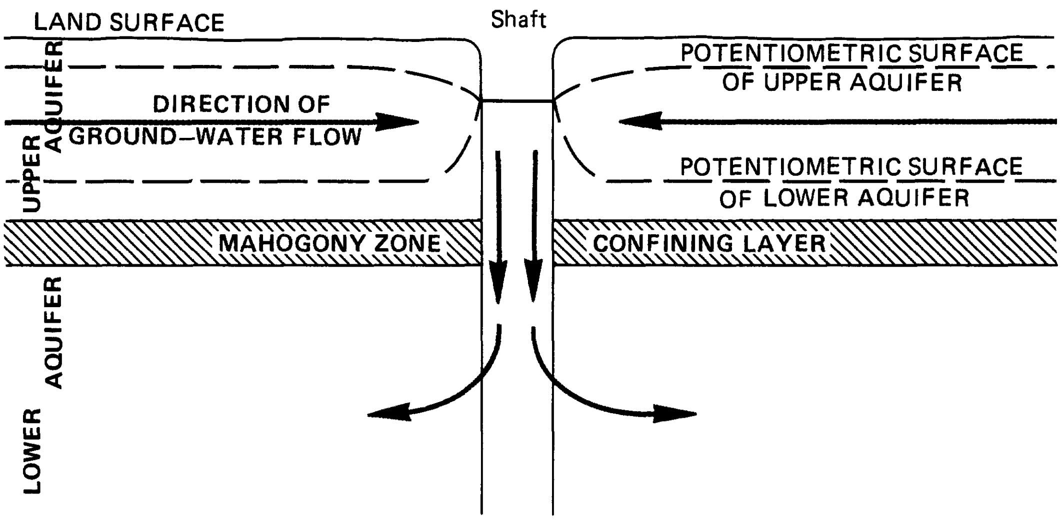


Figure 10.--Ground-water flow system near a single shaft.

Then α = 16,660, and $G(\alpha)$ = 0.2.

The flow from the upper aquifers to the lower aquifers is given by:

$$Q = 3{,}300 \ ft^3/d = 17 \ gal/min.$$

The downward flow in shaft P would be similar. Downward flow in shaft VE would be smaller because the hydraulic-head difference at this site is only about 20 ft (6,460 ft for upper aquifers and 6,440 ft for lower aquifers).

The flow to the upper tunnel also was analyzed. It seems that the upper tunnel will decrease the hydraulic head above the tunnel to the level in the shafts in the upper aquifers (fig. 11). The solution to this analysis, using consistent units, is described by Rorabaugh (1964):

$$q = 2ho\sqrt{ST/t\Pi} \; ; \qquad (3)$$

where

q = the flow to a sink, per unit length, L, on both sides;
ho = hydraulic-head differential, in feet;
T = transmissivity, in feet squared per day;
S = coefficient of storage, dimensionless; and
t = elapsed time, in days.

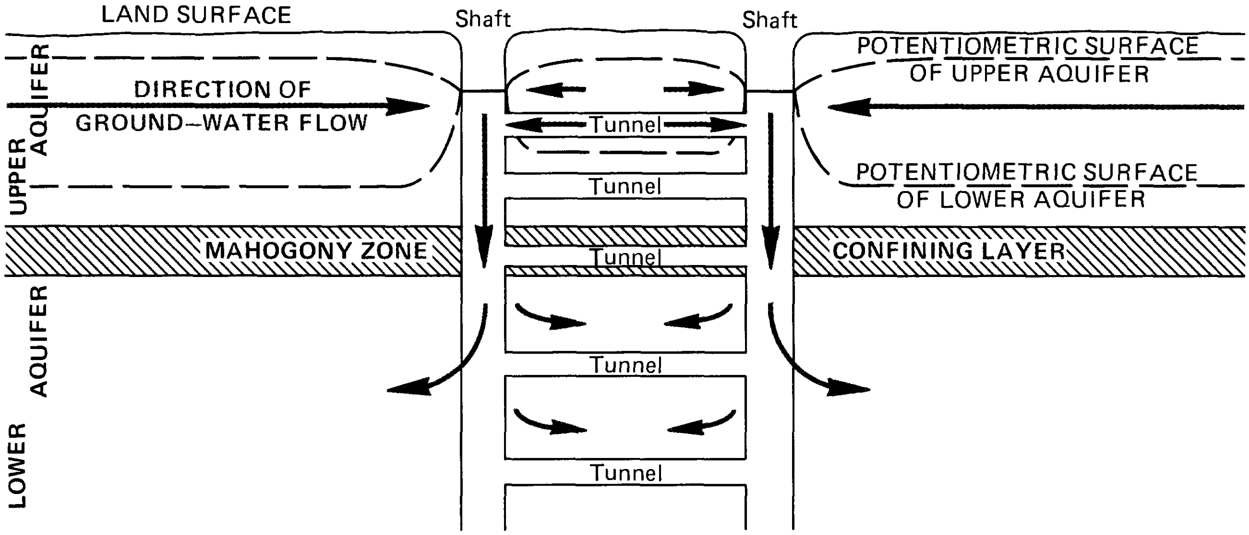


Figure 11.--Ground-water flow system near two shafts connected by several tunnels.

Assume the following quantities:

ho = 11 ft (approximate);
T = 240 ft^2/d (layers 5 and 6);
S = 0.05 (estimated);
t = 1,000 days (assumed); and
L = 250 ft.

Then $q = 1.3\ (ft^3/d)/ft \times 250\ ft = 340\ ft^3/d$;
$= 1.7$ gal/min.

Apparently drainage from tunnels will not be substantial.

OTHER FACTORS AFFECTING THE LOCAL HYDROLOGIC SYSTEM

Solutions of the analytical equations for shafts and tunnels indicate that water from the upper aquifers will drain slowly into the lower aquifers. These solutions were obtained using regional values of aquifer transmissivity and storage. Because of known heterogeneity and anisotropy of these aquifers, local values of aquifer parameters may be different from the regional values used in the calculations. Different aquifer parameters would change the values obtained in the solution of the analytical equations. Likewise, the final hydraulic-head differences between the upper and lower aquifers are not known with certainty.

Because of the natural temperature gradient with depth, the average temperature of water in the lower aquifers is greater than the average temperature of water in the upper aquifers. As a result, convection cells could develop in the shafts because of temperature differences in the upper and lower aquifers. In addition, proposed injection of superheated water into the lower aquifers for solution mining at a location near Tract C-b could increase the temperature and salinity differences between the upper and lower aquifers. The resulting convection cells may allow the relatively saline water in the lower aquifers to migrate into the upper aquifers through the shafts and tunnels.

Finally, changes in the local hydrologic system could result in higher water levels in the lower aquifers compared to the upper aquifers. The associated upward hydraulic gradient could result in flow from the lower aquifers into the upper aquifers. These changes might be caused by effects from discharging wells, injection wells, or decreased natural recharge resulting from climatic changes, such as a sustained drought. An upward hydraulic gradient near the shafts would allow water from the lower aquifers to migrate into the upper aquifers through the shafts and tunnels.

CONCLUSIONS

Flow from the upper aquifers to the lower aquifers through the shafts will be small and will not degrade water quality, according to the analytical analysis. However, because of uncertainties in the flow system and the presence of open shafts connecting the upper and lower aquifers, mixing of water from the aquifers may occur because of other processes that are described below:

1. The hydrologic system may not function exactly as expected because of the anisotropy and heterogeneity of the hydrologic characteristics of the aquifers and the confining layer. For example, local variations of permeability and storage could result in flow in the shafts that would differ from the predicted flow.

2. Water-temperature differences in the shafts caused by the natural temperature gradient may result in convection movement that allows saline water from the lower aquifers to migrate upward and diffuse into the upper aquifers. In addition, the proposed injection of superheated water into the lower aquifers for solution mining at a location near Tract C-b may increase the temperature gradient, salinity, and associated convection and diffusion processes.

3. Human-induced or natural changes in the flow system may reverse the downward gradient and induce water from the lower aquifers to flow upward into the upper aquifers. These changes could include the pumping of wells, injection through wells, a sustained drought, or any other process that results in higher water levels in the lower aquifers compared to the upper aquifers.

REFERENCES CITED

Bradley, W.H., 1931, Origin and microfossils of the oil shale of the Green River Formation of Colorado and Utah: U.S. Geological Survey Professional Paper 168, 58 p.

Cashion, W.B., and Donnell, J.R., 1972, Chart showing correlation of selected key units in the organic-rich sequence of the Green River Formation, Piceance Creek basin, Colorado, and Uinta Basin, Utah: U.S. Geological Survey Oil and Gas Investigations Chart OC 65.

_____ 1974, Revision of nomenclature of the upper part of the Green River Formation, Piceance Creek basin, Colorado, and eastern Uinta Basin, Utah: U.S. Geological Survey Bulletin 1394-G, 9 p.

Jacob, C.E., and Lohman, S.W., 1952, Nonsteady flow to a well of constant drawdown in an extensive aquifer: Transactions of the American Geophysical Union, v. 33, no. 4, p. 559-569.

Papadopulos, I.S., 1966, Nonsteady flow to multiaquifer wells: Journal of Geophysical Research, v. 71, no. 20, p. 4791-4797.

Robson, S.G., and Saulnier, G.J., Jr., 1981, Hydrogeochemistry and simulated solute transport, Piceance basin, northwestern Colorado: U.S. Geological Survey Professional Paper 1196, 65 p.

Rorabaugh, M.I., 1964, Estimating changes in bank storage and ground-water contribution to streamflow: International Association of Scientific Hydrology Symposium Surface Waters, publication no. 63, p. 432-441.

Taylor, O.J., 1986, Simulation of mine drainage for preliminary development of oil shale and associated minerals, Piceance basin, northwestern Colorado: U.S. Geological Survey Water-Resources Investigations Report 86-4011, 25 p.

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