SIMULATION OF MINE DRAINAGE OF OIL-SHALE DEPOSITS, PICEANCE BASIN, COLORADO, U.S.A.

By O. James Taylor
U.S. Geological Survey
Denver, Colorado, U.S.A.

ABSTRACT

The Piceance basin of northwestern Colorado contains large quantities of oil shale and the associated minerals dawsonite and nahcolite. The extensive oil-shale deposits also are fractured-rock aquifers. Natural recharge from precipitation moves through the aquifers and is discharged to streams and springs.

Planned mineral development will require mine drainage at most sites. Several mathematical models have been prepared to simulate the impact of mine drainage on the complex hydrologic system. A revised and improved version of a three-dimensional five-layer finite-difference model simulates streams and springs as head-dependent nodes. This model is used to simulate the reduction and cessation of natural discharge in response to mine drainage. Results of simulation studies of the hydrologic system of the entire basin indicate that the effects of mine drainage will depend greatly on the extent of mineral development.

SIMULATION OF MINE DRAINAGE OF OIL-SHALE DEPOSITS, PICEANCE BASIN, COLORADO, U.S.A.

The Piceance basin extends over an area of 4,140 square kilometers (fig. 1) of northwestern Colorado and contains $190x10^9$ cubic meters of oil shale, the largest single deposit of oil shale known in the entire world. The basin also contains $46x10^9$ metric tons of the minerals dawsonite and nahcolite. The oil shale and minerals are part of the Green River and Uinta Formations of Eocene age that have a maximum combined thickness of about 530 meters.

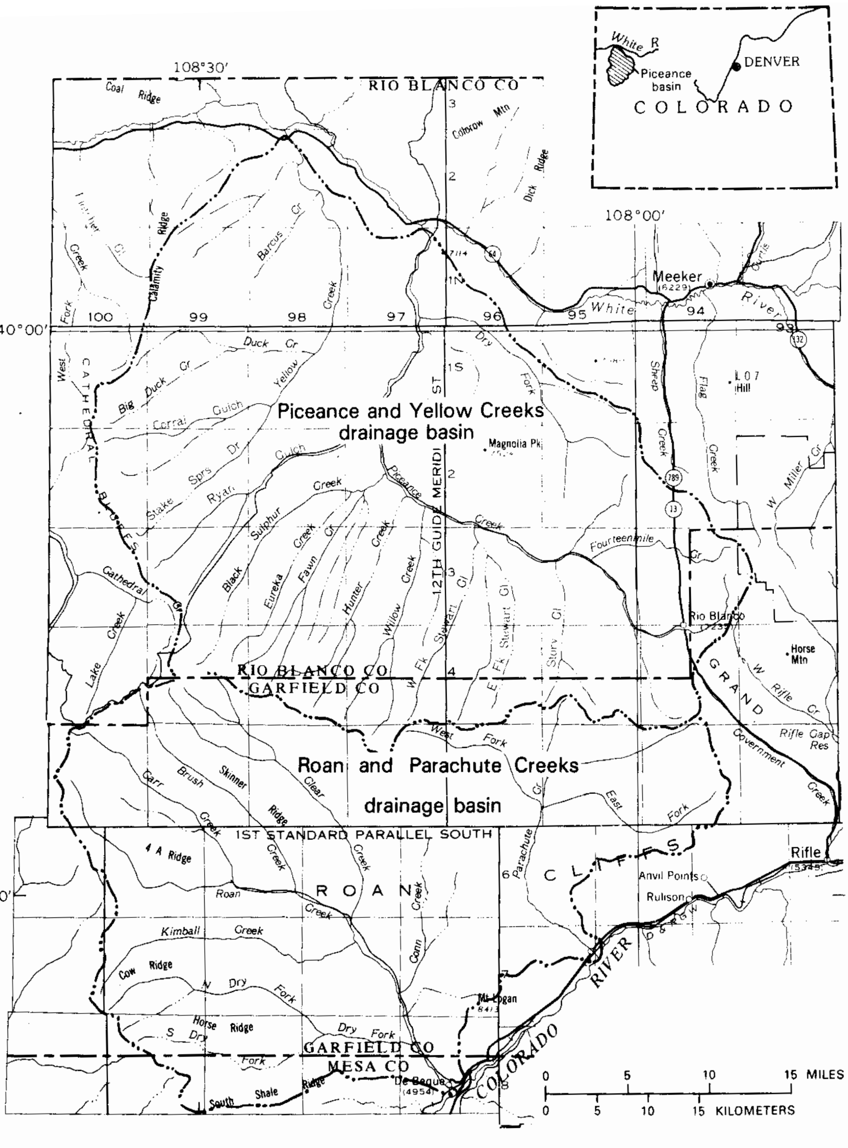

Figure 1.--Major drainage basins of the Piceance basin, northwestern Colorado.

Although the sedimentary strata that contain the minerals have minimal primary permeabilities, these strata were fractured during several periods of tectonic activity. Because of the secondary permeability resulting from the fracture networks, two major aquifers were formed. An upper aquifer exposed at the land surface has an average saturated thickness of about 210 meters. The upper aquifer is underlain by a major confining layer about 50 meters thick. Below the confining layer is another major aquifer that has an average thickness of about 270 meters.

The secondary permeability enabled development of a regional ground-water flow system. Annual precipitation ranges from 300 to 500 millimeters; most natural recharge from precipitation occurs at the higher land-surface altitudes in the basin where precipitation is relatively large, and snow is common. The gradual release of water during snowmelt periods probably facilitates natural recharge, compared to the rapid runoff that occurs during periods of torrential rainfall. The recharged water moves through the fracture networks of the major aquifers, as well as through the major confining layer.

Natural discharge is to streams, but this discharge process differs in the northern and southern parts of the basin (fig. 2). In the north, the

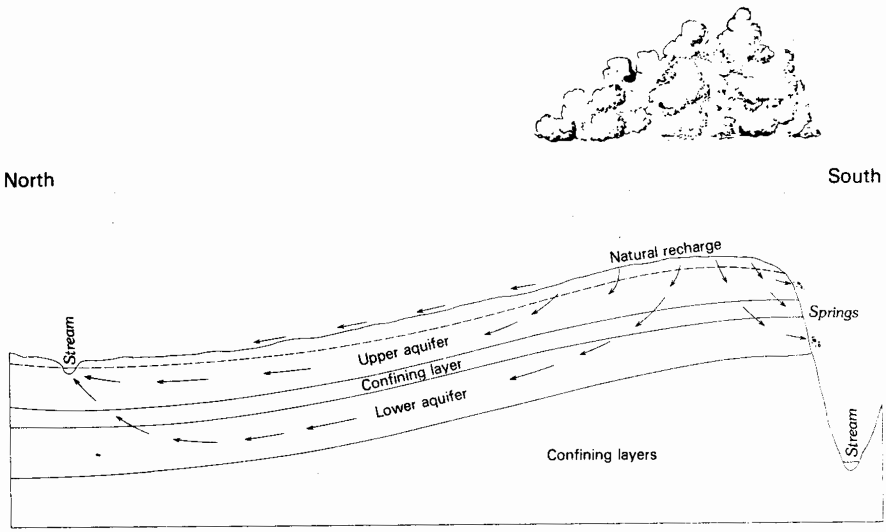

Figure 2.--Natural hydrologic system in Piceance basin.

streams and bedrock aquifers are hydraulically connected through the alluvium. Ground-water discharges (1) from the fractured aquifers through the alluvium and into the stream channel and (2) as springs issuing from aquifers in the stream valleys that also contribute to streamflow. In the south, the stream valleys are incised below the base of the lower aquifer and into deep confining layers. Water is discharged from the aquifers by springs on the valley walls that contribute to streamflow.

Mineral development in the basin will require mine drainage at most sites. The overall effectiveness and impacts of mine drainage have been studied by simulation. Several mathematical models have been prepared to simulate the effects of mine drainage by wells in the Piceance basin. Weeks and others (1974) simulated the hydrologic effects of mine drainage in the northern part of the basin; Robson and Saulnier (1981) simulated solute-transport effects in their analysis of mine drainage.

A three-dimensional, five-layer, finite-difference model was prepared by Taylor (1982) for the basin, using the computer program described by Trescott (1975). This steady-state model was used to analyze aquifer permeability by comparing simulated and measured heads in wells. The model indicated that vertical permeabilities are less than horizontal permeabilities for all model layers, as reported by Robson and Saulnier (1981). A lateral anisotropy in transmissivity for part of the upper aquifer also was detected.

The model described by Taylor (1982) was modified to improve the capability to simulate mine drainage under transient conditions. The principal modification was conversion of the constant-head nodes used to simulate streams and springs in the original model to head-dependent nodes. Discharge at these nodes is a function of the altitude of the head in the aquifer above the stream or spring orifice. If the head is below the stream or spring orifice, the discharge becomes zero. This modification prevents the nodes used to simulate streams and springs from becoming sources of water as simulated mine drainage decreases the head in the aquifers. The required changes in the computer program were designed by Torak (1982).

Additional modifications included the addition to the model of valley-fill alluvium of Piceance and Yellow Creeks, addition of major tributaries, and adjustment of natural recharge. Additional drilling in stream valleys in the northern part of the basin indicated thick deposits of clay in addition to gravel within the valley-fill alluvium. Therefore, the top layer of the original model was divided into two layers in order to add the alluvium to the uppermost layer. Four tributaries of Piceance Creek were designated as head-dependent stream nodes because of evidence of springs that discharge water from the aquifers in these tributary valleys. In addition, the natural recharge rates of several regions were adjusted, resulting in an improved fit between measured and simulated values of streamflow and potentiometric levels.

The resulting modified model appears to simulate the conceptual model of the hydrologic system reasonably well. However, because of the general lack of hydrologic onsite data, especially in the southern part of the basin, this model cannot be considered fully calibrated. Furthermore, current (1985) development is small and transient hydrologic conditions have not been monitored extensively over the entire basin. Therefore, simulation results from the model may be only a rough approximation of the actual response of the hydrologic system to development.

Simulations of mine drainage by pumping for oil-shale development indicate changing impacts due to the amount of development. Small development and associated declines in the potentiometric surfaces likely will result in decreases in discharge to streams in the north and decreases in spring discharge in the south (fig. 3). Moderate

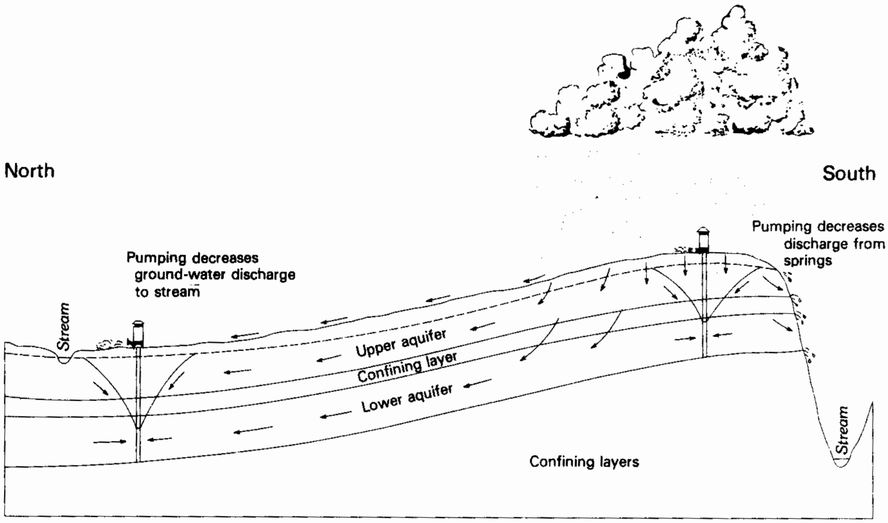

Figure 3.--Effects of small oil-shale development on hydrologic system.

development likely will result in further decreases in natural discharge to streams in the north, enabling infiltration of surface runoff in some reaches. Moderate development likely will further decrease discharge from springs in the south (fig. 4). The effects of intense development will result in extensive aquifer drainage. Additional model modification and improved hydrologic data will be necessary to simulate intense development in order to account for the resulting changes in aquifer transmissivity and storage coefficient.

The model discussed in this report will be used to simulate various rates of locations of mine drainage and to simulate injection for temporary storage of water in the aquifer. It should help to design methods for efficient mine drainage that consider streams, springs, and various types of interference among mine-drainage pumpage patterns.

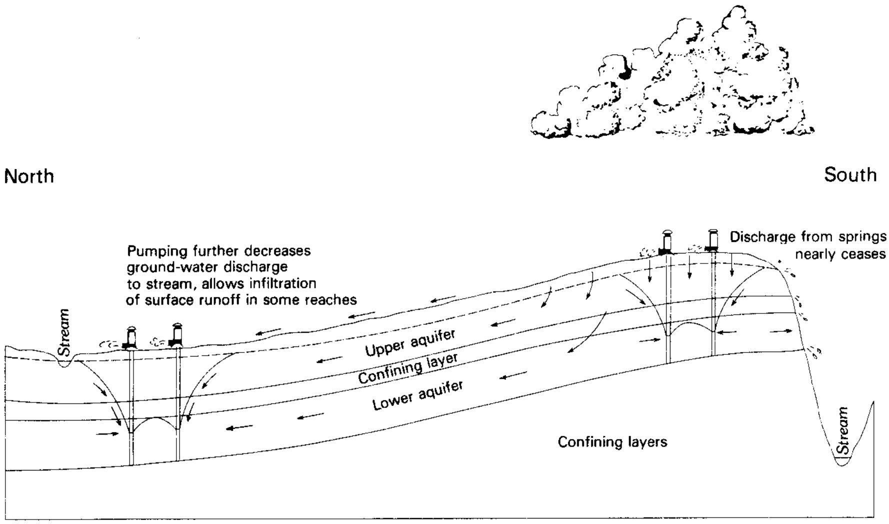

Figure 4.--Effects of moderate oil-shale development on hydrologic system.

REFERENCES

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.

Taylor, O. J., 1982, Three-dimensional mathematical model for simulating the hydrologic system in the Piceance basin, Colorado: U.S. Geological Survey Water-Resources Investigations Open-File Report 92-637, 35 p.

Torak, L. J., 1982, Modifications and corrections to the finite-difference model for simulation of three-dimensional ground-water flow: U.S. Geological Survey Water-Resources Investigations Report 82-4025, 30 p.

Trescott, P. C., 1975, Documentation of finite-difference model for simulation of three-dimensional ground-water flow: U.S. Geological Survey Open-file Report 75-438, 106 p.

Weeks, J. B., Leavesley, G. H., Welder, F. A., and Saulnier, G. J., Jr., 1974, Simulated effects of oil-shale development on the hydrology of Piceance basin, Colorado: U.S. Geological Survey Professional Paper 908, 84 p.