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Management of the Hydrologic System in Areas Subject to Coal Mining Activities

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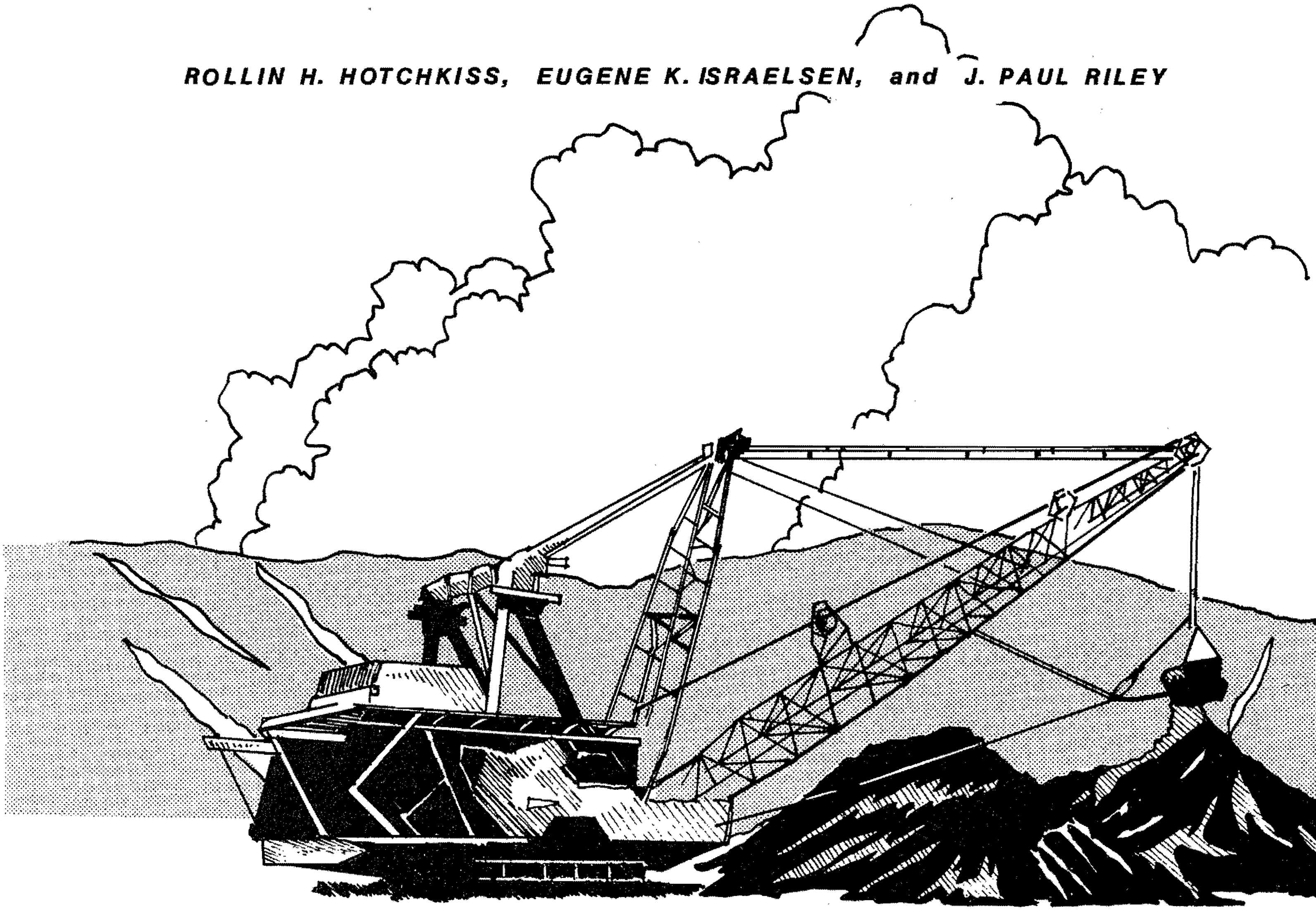

Utah Water Research Laboratory
College of Engineering
Utah State University
Logan, Utah 84322
October 1980

WATER RESOURCES PLANNING SERIES
UWRL/P-80/05

MANAGEMENT OF THE HYDROLOGIC SYSTEM IN AREAS SUBJECT TO COAL MINING ACTIVITIES

by

Rollin H. Hotchkiss
Eugene K. Israelsen
and
J. Paul Riley

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ABSTRACT

Publicity given to the detrimental effects of mining activities on the environment has tended to overshadow somewhat the hydrologic opportunities and benefits that could be associated with these activities. For example, many areas disturbed by surface mining have proved to be excellent recharge areas for groundwater aquifers. The degree to which mine sites can be exploited to improve management of the hydrologic system depends on both the local geology and the mining techniques used.

The report examines the effects of present mining activities on the associated hydrologic system, and identifies specific mining procedures and management techniques which not only minimize negative hydrologic impacts of mining operations, but which also enhance the value of the hydrologic system in terms of existing and potential social uses. Thus, the results of the research contribute to the solution of present and future hydrologic problems (both quantity and quality) associated with coal mining in the western U.S. Emphasis is placed on sites which are representative of both existing and future coal mining areas.

The specific objectives of the study are to:

1. Evaluate the potential for using underground coal mines to:

a. Tap previously inaccessible groundwater supplies.

b. Reduce the salt load to the Colorado River by decreasing the contact of groundwater with salt-bearing geologic formations.

c. Store water in abandoned mines.

2. Consider the potential effects of underground coal mines on water resources.

3. Evaluate the potential of using surface mined areas to collect surface runoff and thus:

a. Reduce the sediment loads to the Colorado River.

b. Enhance water storage in the basin.

Each of the preceding objectives is addressed and discussed by the report in terms of actual coal mines in central Utah. The study suggests not only ways of reducing negative hydrologic impacts of mining operations, but also operational and management mining techniques which will enhance the social use value of the hydrologic systems, and thus, in fact, create hydrologic opportunities.

Keywords: Hydrology*/Coal mining*/Water supply*/Water quality/Impoundment ponds/Total containment*/Hydrologic opportunities

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CHAPTER I

INTRODUCTION

In 1977 the United States produced 685 million tons of coal. Due to the nationwide effort to achieve energy independence, this figure is expected to double by 1985 (Nielson 1978). But this increased emphasis on coal production has raised many concerns about its environmental consequences.

Background

The coal mining industry of the United States has been accused throughout its history of seriously disrupting the environment. Typical is a statement by the House Interior Committee's Subcommittee on Energy and the Environment:

> Acid drainage which has ruined an estimated 1,000 miles of streams, the loss of prime hardwood forest and the destruction of wildlife habitat by strip mining, the degrading of productive farmland; recurrent landslides, siltation and sedimentation of the river systems; the destructive movement of boulders, and perpetually burning mine waste dumps--these constitute a pervasive and far-reaching ambience. Tragically, coal mining in America has left its crippling mark upon the very communities which labored most to produce the energy which once impelled the Nation's industrial plant and now generates much of its electrical power (Hamilton 1977, p. 55).

Hamilton (1977), quoting Primack, infers that these detrimental side effects of coal mining have been the result of poor management practices:

> Strip mining has been allowed to run rampant in Appalachia because that's the way the coal industry wanted it. The coal industry has long owned most of the land, controlled most of the economy and courthouses as well, and instead of mining coal in a manner responsive to local needs, the industry chose--and was allowed to mine it as quickly, cheaply and easily as it could.
>
> The results are scars from stripping, thousands of unnecessary deaths in underground mines and from black lung, and inadequate social services because coal companies have never been assessed nor paid proper taxes (p. 55).

Identification of the Problem

While it is true that careless coal mining methods can be destructive environmentally, the mining can when properly planned take advantage of a number of opportunities with environmental and economic benefits. The consequences of taking the land surface apart can range from disastrous to beneficial depending on how it is put back together afterwards. Specific opportunities for benefiting by changing the hydrologic regime so as to be better able to manage groundwater resources are:

1. Many surface mined lands have proven to be excellent groundwater recharge and storage areas, increasing infiltration and resultant base flows during dry periods (Corbett 1978).

2. Underground mines may tap previously inaccessible groundwater aquifers and provide a new source of water to surrounding communities (Brauer 1977).

3. Abandoned underground mines may serve as underground water storage reservoirs and effectively eliminate the high evaporation losses associated with surface reservoirs.

4. Underground mines may tap aquifers at points where the water can be conveniently withdrawn for beneficial use upstream of where it would otherwise be polluted by the salinity in marine sediments or irrigation return flows.

Purpose and Study Area

Purpose

The purpose of this study is to identify and evaluate opportunities to achieve water resources management benefits while coal mining in the State of Utah and to identify management practices that would best develop these benefits. The variety of beneficial management alternatives while coal mining is underway is illustrated by Figure 1.1. The dashed lines suggest opportunities for using water from active mines, either directly or after any necessary treatment. After the mining is finished, opportunities exist for increasing interception, using the volumes where coal has been removed for storage, and delivering the outflowing water where it can be best used. In this study sites are

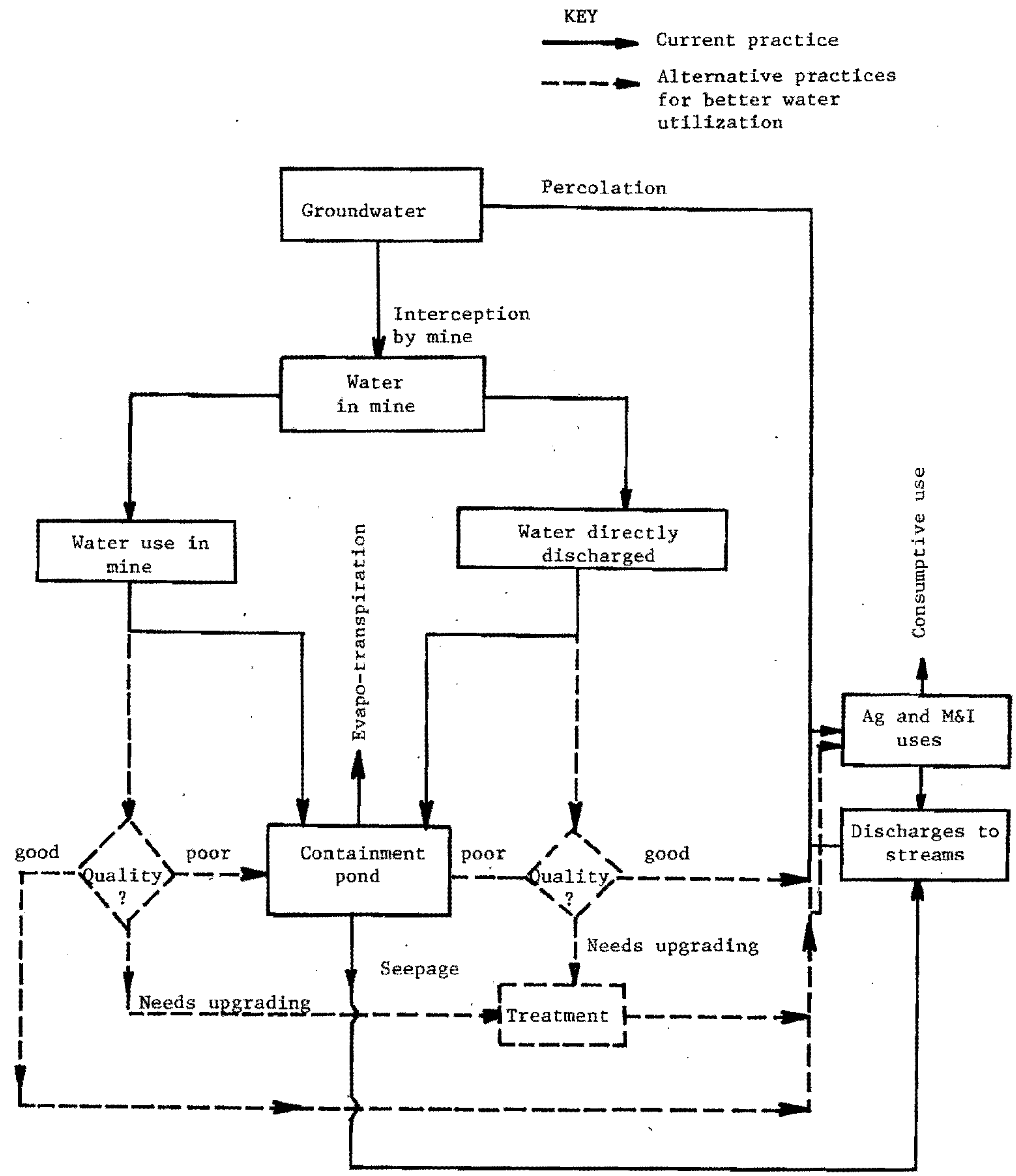


Figure 1.1. Some possible alternatives in the management of water discharge from coal mining operations.

examined which represent both existing and future surface and subsurface mine developments. The specific opportunities considered are:

1. The potential of using underground coal mines to:
   a. Tap groundwater supplies.
   b. Reduce the salt load input to the Colorado River by decreasing the contact of groundwater with salt-bearing geologic formations.
   c. Store water in abandoned mines.
2. The potential effects of underground coal mines on groundwater movement, mixing, and quality.
3. The potential of using surface-mined areas to collect surface runoff and thus:
   a. Reduce the sediment loads to the Colorado River.
   b. Augment water storage in the basin.

Study area

This study examined lands subject to surface and underground coal mining within Utah. Doelling (1972) identified 21 different regions within the state that contain sufficient coal for mining to be economical. Of these 21 coal fields, three--the Book Cliffs, Wasatch Plateau, and Emery fields--contain 38 of the 50 areas described in permits to conduct coal mining operations currently on file with the Utah Division of Oil, Gas, and Mining, the agency that regulates mining operations in Utah. Maps of the Book Cliffs, Wasatch Plateau, and Emery coal fields are depicted in Figures A.1, A.2, and A.3 in Appendix A, and the producing and non-producing coal mines are located on each map. Table A.1 describes the type, location, size and status of all 50 coal mines as registered with the Division of Oil, Gas and Mining.

The study areas for assessing opportunities to reduce the salinity and sediment loads to the Colorado River are restricted to lands subject to coal mining activities within the Colorado River Basin. Assessment of the potential for using underground coal mines to tap previously inaccessible groundwater supplies is further restricted by the availability of data to the Book Cliffs, Wasatch Plateau, and Emery coal fields.

Significance of the Research

Significance of coal

Coal represents 80 percent of the nation's proven energy reserves and, therefore, is expected to play an important part in the quest for U.S. energy independence (Civil Engineering 1977a).

> Coal must become the nation's chief tool for increasing energy self-reliance. Coal is abundant. The technology to use it is available today. There is an existing production and distribution base to build on. Finally, coal can be converted into a wide range of fuel products or used as feedstock for chemical production (p. 43).

In the spring of 1977, President Carter unveiled a national energy plan which states in part:

> We must conserve the fuels that are scarcest and make the most of those that are most plentiful. We cannot continue to use oil and gas for 75 percent of our consumption when they make up only 8 percent of our domestic reserves. We need to shift to plentiful coal ... (Civil Engineering 1977b).

This shift to coal is further emphasized by President Carter's goal of "increasing coal production on an annual basis by at least 400 million tons" (p. 51).

Coal expansion in Utah

The Utah coal industry expects a substantial increase in coal production. Production increased 102 percent from 1970 to 1977 (U.S. Department of the Interior 1978), and sources estimate a 400 to 600 percent increase through 1987 (Office of Legislative Research 1976, Nielson 1979, and Division of Coal Production Technology 1979) (see Figure 1.2). Such increases in coal production will bring proportional increases in local population and water demand.

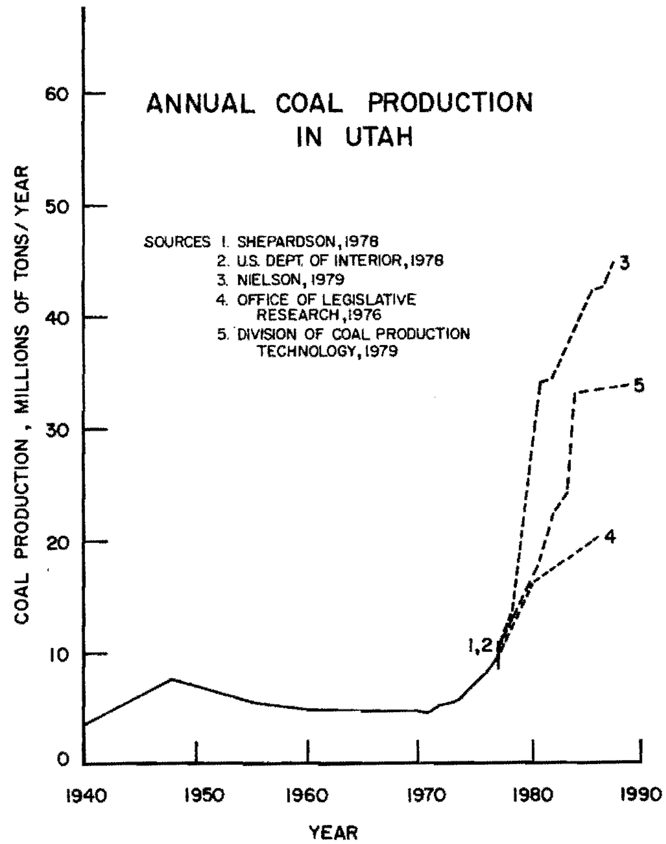


Figure 1.2. Annual coal production in Utah.

Critical water supply

Current water supplies for the coal mining areas of Utah are barely adequate (Riley et al. 1978). A major expansion in coal mining and the industrial and population growth it will attract will further strain the present water supply system. New sources of water must be found to meet future demands. Intercepted groundwater from mining development may be developed into an important future source.

Water storage

Water must be stored for a firm supply during dry periods. Storage in surface reservoirs in the coal mining areas of Utah is done only with high evaporation losses. Underground storage in abandoned mines would eliminate evaporation losses and may prove economical.

Water quality

Most of the Utah coal fields lie within the Colorado River Basin (see Figure 1.3), where much concern has been expressed over rising salinity and sediment concentrations. Annual downstream damages from salinity alone have been estimated at $230,000/mg/l (UWRL 1975). Any reduction in salt or sediment load to the Colorado River would be a benefit.

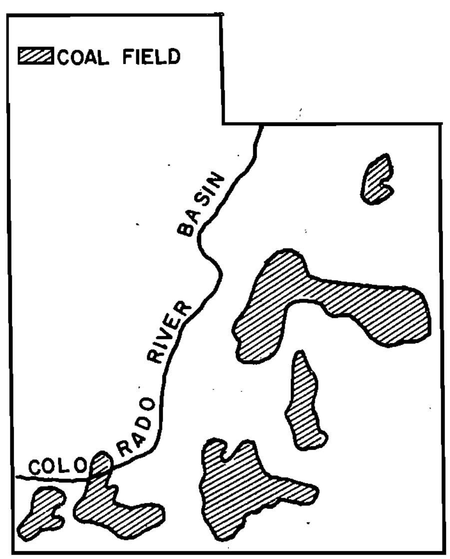


Figure 1.3. Utah coal fields within the Colorado River Basin.

Mining Methods

Coal can be mined by either underground or surface methods, and each has a number of submethods. They are:

1. Underground coal mining: Removal of coal from beneath the surface of the earth without disturbing the surface. Underground mining is achieved by one of the following methods:

a. Room and pillar: In the initial stage of mining the coal plane, coal pillars are left which are one to three times as wide as the room formed by the extracted coal. Once the end of the seam to be mined is reached, a retreat is made in which many of the pillars are removed. Roof collapsing follows the retreat. Average rate of extraction is 58 percent.

b. Long wall mining: Two or more initial equipment passageways are cut deep into the coal seam. Coal is extracted by removing the entire seam between pairs of passageways in one operation along a long wall or working face. The workings advance in a continuous line which is usually 200 to 600 feet in length, but reportedly may exceed 1,000 feet. Self-advancing power supports are commonly used to keep the longwall face open and prevent roof falls. The supports are advanced as mining progresses, and the roof is allowed to break and cave immediately behind the support line. Average rate of recovery is about 80-85 percent.

c. Shortwall mining: Similar to longwall mining, except that conventional room and pillar continuous mining equipment is used, and the mining advances along a 100-200 foot face (National Academy of Sciences 1974 and U.S. Environmental Protection Agency 1975).

2. Surface mining: Removal of coal first exposed to the earth's surface by stripping away the overburden, mining the exposed coal, and replacing the overburden.

CHAPTER II

THE POTENTIAL FOR USING UNDERGROUND COAL MINES TO TAP GROUNDWATER SUPPLIES

It is the objective of this chapter to evaluate the potential for using underground coal mines to tap groundwater supplies. The first step is to predict approximately how much groundwater will be intercepted at yet undeveloped mine sites in the Wasatch Plateau, Book Cliffs and Emergy coal fields of Utah (see Figure 1.2). The introduction reviews past and present beneficial uses of groundwater intercepted by mines and discusses the future need for water in the study area. A review of previous attempts to predict groundwater recharge and interception follows. The methodology used in this study to predict groundwater interception by underground mines is then presented.

Introduction

Increasing coal production in Utah will increase the demand for water for industrial and municipal purposes. An important contributor to water supply may be coal mines themselves as they intercept groundwater and make it available for beneficial use.

Need for water

Coal production in central Utah is expected to increase from 8.57 million tons per year (mty) in 1978 to 24-44 mty in 1990 (Nielson 1979, U.S. Geological Survey 1978d). Associated with this increase in coal production will be a proportional increase in the demand for water. The U.S. Geological Survey (1978d) estimates that to increase coal production to 24 mty will require at least 8,000 acre-feet of water annually. Locating and developing such water in the arid climate of central Utah is a concern of both industry and government.

Water production from coal mines

Coal mines may play an important role in the development of needed future water. Currently, underground coal mines in central Utah discharge a total of 5,900 acre-feet per year of intercepted groundwater (Israelsen, personal communication 1979). As mining increases, the amount of intercepted water will also increase, making more water available for beneficial purposes. The following are examples of how underground coal mines in the study area have beneficially used intercepted groundwater:

1. Dust suppression at the working face of the coal seam.
2. Bathing water (Intermountain Consultants and Planners 1977a).
3. In-mine-drinking water (Ibid).
4. Cooling towers at a power plant (Ibid).
5. Backpumping refuse into the mine (Shoemaker 1962).
6. Irrigation of public land (Brauer 1977).
7. Municipal water supply (Ibid).

In addition, Skelly and Loy (1978) and the U.S. Geological Survey (1978b) proposed that discharged minewater in central Utah may be used for enhancing waterfowl and fish habitats. Thus, groundwater intercepted in underground coal mines in Utah has been considered for and put to many beneficial uses, and could be an important future water source for the state.

Methods for Predicting Mine Groundwater Interception

Predicting how much water recharges mine overburden and is later intercepted by mines in the study area is complicated by a lack of data and complex area geology. Past estimates have been based on empirical extrapolations or water budget equations.

Estimates based on water budget equations

Several studies have estimated groundwater recharge in the study area using a simplified version of the water budget equation:

$$GWR = P - ET - SR$$

where

GWR = groundwater recharge
P = precipitation over the area
ET = evapotranspiration
SR = surface runoff

Cordova study. Cordova (1964) estimated groundwater infiltration and exportation from the headwaters of the Price River using the water budget approach. Annual precipitation over the 32-square mile area was estimated to be 22 inches or 38,000 acre-feet. Evapotranspiration was assumed to consume 65 percent of the annual precipitation, or 25,000 acre-feet, and streamflow was estimated at 6,000 acre-feet per year. Groundwater recharge was then calculated to be 7,000 acre-feet per year. Of this quantity, about 3,000 acre-feet per year is discharged from springs and wells, leaving approximately 4,000 acre-feet annually available for subsurface flow out of the study area.

Price and Arnow study. Price and Arnow (1974), in a study of the groundwater resources of the Upper Colorado River Basin, also used a water budget equation. They estimated precipitation over the region to average 95 million acre-feet per year. Of this water, "practically all ... is consumed at or near the place of fall by sublimation and evapotranspiration or becomes overland runoff" (p. C9). Regarding the deep percolation component of the budget, they stated, "only about 4 percent, or about 4 million acre-feet is estimated to become groundwater recharge. This includes percolation through the soil zone as well as seepage from streams and lands irrigated by streams" (p. C9).

Price and Miller study. Price and Miller (1975) in a study of the southern Uintah Basin, estimated groundwater recharge over the area as did Price and Arnow in 1974, and then modified the estimate according to area geology:

> Because of the predominantly fine-grained nature and low permeability of the rocks in the recharge area, percolation rates are very slow. It is assumed, therefore, that most recharge occurs during the winter when rain and storms are more widespread and of longer duration. Therefore, it is estimated that only about 100,000 acre-feet or about 3 percent of the estimated average annual precipitation becomes groundwater recharge (p. 28).

Estimates based on empirical extrapolation

While the previously quoted studies estimate volumes of groundwater recharge over an area, not all of this water could be intercepted by coal mines. Water once infiltrated, may travel entirely outside of a mine area. Perhaps for this reason, several studies have estimated groundwater interception at new mines based solely on the experience of other mines in the area.

Bureau of Land Management study. In the draft Environmental Statement: Emery Units 3 and 4 (1979), the Bureau of Land Management anticipated how much water may be generated within the proposed mine: "It is anticipated that, after early development and based on water production from the adjacent Deer Creek mine, as much as 400,000 gallons daily of excess water would be generated within the mine" (p. 1-27).

U.S. Geological Survey report. The U.S. Geological Survey (1978d) in a draft environmental statement of the B Canyon Mine in the Book Cliffs area estimated a low limit of groundwater interception when they stated: "Mining experience in the area indicates that water would become available within the mine as mining progresses; mine water then would be used for industrial needs, 250,000 gpd, and would be stored in a tank on the plantsite" (p. BC-10).

Limitations of past approaches

Both the method using water budget equations and the method of empirical extrapolation have severe limitations. While the water budget equations estimate groundwater recharge, they over state mine groundwater interception as no accounting is made for the direction of flow once water has infiltrated into the ground. Water may be channeled out of the area at a subsurface elevation above the mine or flow on down to an aquifer that is not intercepted. The water budget approach is additionally constrained by the lack of data for estimating the input precipitation, evapotranspiration and surface runoff. For example, the Price and Miller study estimated precipitation from isohyetal maps and then assumed that evapotranspiration and surface runoff accounted for "nearly all" of the precipitation.

The empirical approach attempts to overcome the limitations of the water budget equation by using data on the quantity of water intercepted by nearby mines. While certainly applicable in areas of geologic homogeneity, this method is unreliable in areas where faulted or other complex geology confines movement of underground water. For example, an estimate that 400,000 gallons per day of groundwater would be intercepted by a new mine was based on nearby experience at Deer Creek. Approximately equidistant from the new mine site, however, are three other mines that intercept no groundwater. Obviously, local geology plays an important role in mine groundwater interception that must be considered.

Methodology of this Study

The above methods for estimating how much water will be intercepted by an underground mine are constrained by 1) inadequacies of hydrologic data for estimating deep percolation from a water balance at the ground surface and 2) incomplete descriptive information on rock strata for establishing the direction and rate of movement of the deep percolation. The approach of this study was to work backwards from existing mines in order to determine the factors controlling the amounts of water observed being intercepted. Relationships between these factors and the amounts of mine-intercepted water would then be used to predict interception rates at other mine sites.

In order to understand the origin of intercepted groundwater in the study area, the following steps were accomplished:

1. Assemble from coal companies and other sources, information on the locations and extent of coal development and the quantity of intercepted groundwater in mines in the study area.

2. From these data, calculate the equivalent depth of intercepted groundwater per unit of mine area per year for mines in the study area. This depth of interception per year is a guide to understanding the origin of groundwater. If, for example, a mine intercepts an equivalent of 50 inches of water per year in an area of 12 inches of annual precipitation, it would be evident that the intercepted groundwater was not all coming from deep percolation from the overlying ground surface. A significant amount would have to be moving laterally into the area.

3. Assemble pertinent data regarding geology, hydrology, and the history of mining developments in the study area.

4. Use these data to establish relationships for predicting groundwater interception at undeveloped mine sites from infiltration conditions at the ground surface and local geology.

Results

At least nine mines in the study area have a history of intercepting groundwater. Descriptive data shown in Table 2.1 include the mine names, their geologic and geographic locations and elevations, the years in operation, mined acreage, discharge data and normal annual precipitation over the area. Included also is the calculated equivalent depth over the mined area of intercepted groundwater based on the discharge records from the mine. Information to follow on the nine mines includes local geologic cross sections and fault locations, theories of the origin of intercepted groundwater, and estimates of how much groundwater may be expected to be intercepted as mining continues.

Emery deep mine

Geographical and geological setting. The Emery deep mine is located in the western flank of the San Rafael Swell approximately 4 miles south of Emery, Utah. The mined coal seam is located in the Ferron sandstone member of the Mancos shale group, dipping from 2 to 4 degrees to the west (Doelling 1972) (see Figure 2.1). The Ferron sandstone is confined above by the Blue Gate shale and below by the Tununk shale. Joe's Valley fault zone, a major faulting system, lies west of the mine near the base of the Wasatch Plateau.

Hydrologic setting. Three perennial streams flow in the vicinity of the mine. Muddy Creek and Quitchupah Creek are fed from precipitation originating over the Wasatch Plateau to the west, while Christiansen Wash drains return flow from locally irrigated lands. Muddy and Quitchupah Creeks also receive substantial volumes of agricultural return flow in the mine area. Total dissolved solids (TDS) concentrations of these surface waters near the mine average 1,750 parts per million (ppm) for Muddy Creek and 5,000 ppm for Quitchupah Creek and Christiansen Wash. Numerous flowing boreholes in the area from the Ferron sandstone average 1,000 ppm TDS (Consolidation Coal Company 1978).

Intercepted groundwater. The mine intercepts and discharges groundwater at an average rate of 425 gallons per minute, which when distributed over the mined acreage on an annual basis is the equivalent of 26 inches of groundwater interception. Approximately 30 percent of the water originating within the mine seeps from sealed off areas and has a TDS concentration of 6,500 ppm (personal communication, confidential source[1]). The sealed off portion of the mine lies from 125 to 200 feet below local surface waters.

[1]Much information assembled for this study came from sources who preferred not to be specifically identified. These references are cited as "personal communication, confidential source" throughout the report.

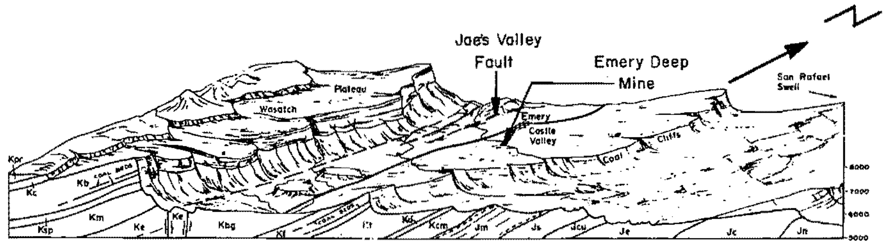


Figure 2.1. East-west cross section and physiographic diagram of the Emery coal field and surrounding area (taken from Doelling 1972, Vol. 3, p. 428).

Table 2.1. Groundwater discharge from underground coal mines in central Utah.

Mine Name	Portal Location			Portal Elev. Feet	Mined Acres	Years of Operation	Geologic Formation	Discharge Data	Source of Discharge Data	In/yr in Interception	Normal Annual Precipitation, Inches
	Town-ship	Range	Section								
Emery Deep	22S.	6E.		6000[c]	320[c]	88	Ferron Sandstone[b]	500 Gal/min 362 Gal/min	Skelly and Loy (1978) Personal correspondence	30.2 21.9	7.2
Sunnyside Complex	14S.	14E.	32,NE¼SE¼SW¼	6760[c]	6400[c]	80	Blackhawk[b]	820 Gal/min (vari.) 1030 Gal/min 687 Gal/min	Personal correspondence Brauer (1977) Skelly and Loy (1978)	2.5 3.1 2.1	12-16
Geneva Complex	16S.	14E.	4,Ctr,NE¼SE¼	6800[c]	3200[c]	38	Blackhawk[b]	450 Gal/min	Brauer (1977)	2.7	12-16
Utah No. 2	13S.	7E.	8,SE¼SE¼SE¼	8040[a]	76[a]	4	Blackhawk[b]	262 Gal/min 628 Gal/min	Personal correspondence Brauer (1977)	66. 160.	18
Belina No. 1	13S.	7E.	30,NW¼NW¼NW¼	9035[a]	21.6[a]	2	Blackhawk[b]	6.2 Gal/min	Personal correspondence	5.6	27
Hiawatha Complex	16S. (Abandoned	8E.	8,SE¼NE¼SE¼ Mohrland Portal)	7720[c]	5760[c]	89	Blackhawk[a]	845 Gal/min 450-1125 Gal/min	Personal correspondence Brauer (1977)	2.8 1.5-3.8	16
Deer Creek	17S.	7E.	10,NE¼NE¼SE¼	7500[c]	1050[c]	28	Blackhawk[b]	175 Gal/min	Intermountain Consultants and Planners (1977a)	3.2	28
Wilberg	17S.	7E.	27,NW¼NW¼NE¼	8000[c]	180[a]	5	Blackhawk[b]	94 Gal/min 100-200 Gal/min	Brauer (1977) Intermountain Consultants and Planners (1977a)	10.1 16.1	20
Gordon Creek No. 3	13S.	8E.	16,SE¼NE¼SW¼	7564[a]	120[a]	4	Blackhawk[a]	193 Gal/min 673 Gal/min	Personal correspondence Brauer (1977)	31.1 109.	21

[a]Personal communication, confidential source.

[b]Doelling (1972, Vol. 3).

[c]Estimated from topographic map.

The balance of intercepted water enters the active portion of the mine directly through joints in the roof and has an average TDS concentration of 1,000 ppm. Discharged minewater averages 4,000-5,000 ppm of total dissolved solids (Utah Division of Health 1978).

Origin of groundwater. Studies conducted for the Emery mining and reclamation plan (Consolidation Coal Company 1978) strongly suggest that the Ferron sandstone in which the Emery deep mine is located is a confined aquifer. Figure 2.2 depicts the net flow of the Ferron aquifer in the vicinity of the mine and a cross section taken through the aquifer and mine. Flow lines suggest that groundwater enters the mine from the Ferron sandstone. The similarity between the TDS levels of the water entering the mine through roof cracks and that of flowing boreholes from the Ferron sandstone reinforce this concept. The equivalent annual interception rate of 26 inches, when compared to the normal annual precipitation in the area of 7.2 inches, also suggests that the mine intercepts more water than could percolate vertically from surface precipitation.

The cross section in Figure 2.2 also shows an unconfined aquifer near the surface in quaternary alluvium and river terrace deposits. The high TDS levels of water flowing from the sealed off portion of the mine suggest that agricultural return flow from Quitchupah Creek or Christiansen Wash also contribute to the groundwater intercepted by the mine.

Based on these data it would appear that approximately 70 percent of the groundwater intercepted at the Emery deep mine, or about 300 gallons per minute, originates from the Ferron sandstone, while up to 30 percent is the result of infiltration from surface waters.

Future groundwater interception. Groundwater interception should increase as mining continues to expose more of the aquifer in the Ferron sandstone. Based on current rates of interception in the aquifer, a discharge increase of about 1 gallon per minute per acre of new development may be expected.

Sunnyside and Geneva mines

Geographic and geologic setting. The Sunnyside and Geneva mines are located in the central Book Cliffs coal field, in Townships 14 and 16 South and Range 14 East (see Figure 2.3). Both mines remove coal from 300-2,000 feet below the surface in a seam overlain by the Castlegate sandstone and overlying the Starpoint sandstone of the Mesaverde group. The rocks dip from 4 to 12 degrees towards the northeast.

According to Doelling (1972),

> ... faulting is not much of a problem in the Book Cliffs ... except for some medium displacement faults near Sunnyside, faulting is local and of minor displacement.... The most serious group of faults lies in the area of Sunnyside where two steeply dipping fault sets occur; the first trends North-northwest, the second East-north-east. Although a hindrance to mining, they fortunately are not too closely spaced (Vol. 3, pp. 327, 262-263).

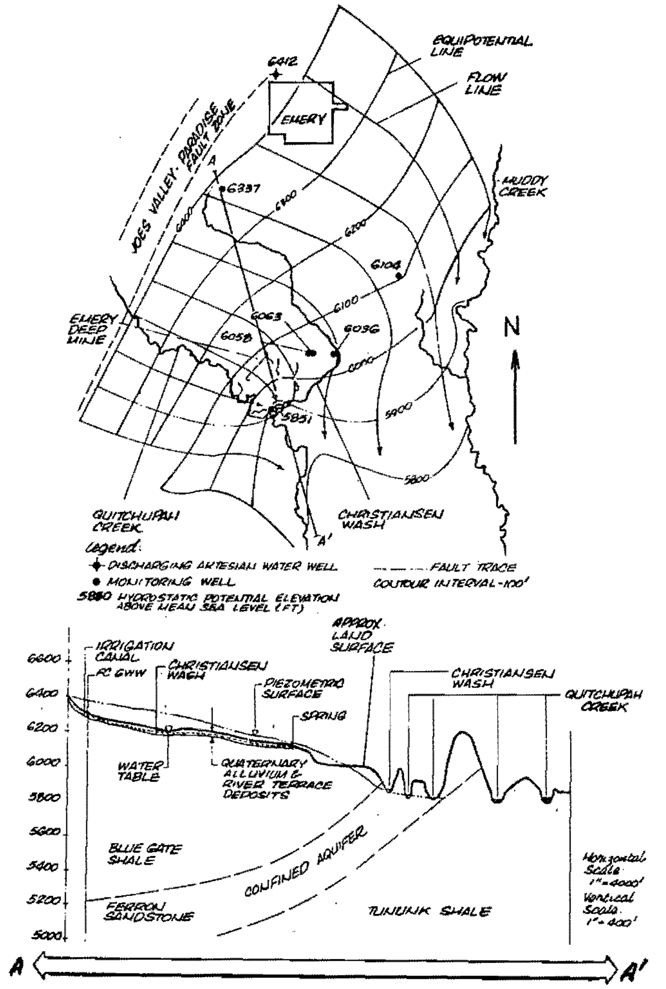


Figure 2.2. Flow net and potentiometric surface of Ferron aquifer (taken from Consolidation Coal Co. 1978, p. 27-28).

The mining is inducing vertical cracking in the overlying Castlegate sandstone. In 1963 and 1966 tension and compression cracks hundreds of feet long and up to 3 feet wide near the coal outcrop separating the Geneva mine and the Book Cliffs mine to the south (now closed) were observed (Dunrud 1976). The cracks surfaced through approximately 800 feet of overburden.

Hydrologic setting. Both mines are in an area which receives approximately 12-16 inches of precipitation annually (Jeppson et

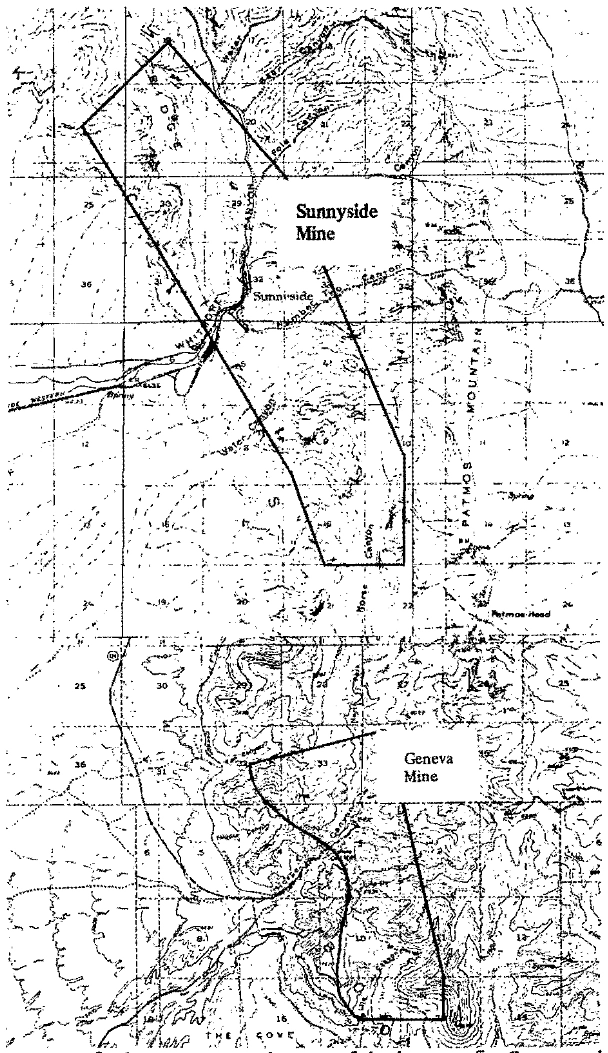


Figure 2.3. Approximate limits of Sunnyside and Geneva mines, Utah (Sunnyside and Woodside quadranges from U.S. Geological Survey).

al. 1968). Doelling (1972), speaking of subsurface water in the Book Cliffs, states:

> Precipitation that falls as rain or snow above the cliffs makes its way into the soil unless the rainfall is torrential. Winter storms are the best sources of subsurface moisture; the moisture infiltrates the more permeable and porous rocks which include sandstones and limestones. Summer storms are largely torrential. The moisture collects in dry creek beds which lead into larger and larger washes until a permanent stream is reached. Non-torrential summer rain is quickly transpired or evaporated and little feeds the subsurface reservoir (Vol. 3, p. 325).

Concerning water quality, Doelling continues:

> During migration through rocks the moisture picks up chemical matter, the more impermeable the rock, the more chemical is picked up .... Shales usually impart the greatest chemical content to the water (Vol. 3, p. 326).

Intercepted groundwater. The Sunnyside and Geneva mines annually intercept equivalent averages of 2.6 and 2.7 inches of groundwater, respectively. Interception appears to follow seasonal patterns of surface water flow (personal communication, confidential source). Average TDS concentrations of water intercepted in the Sunnyside and Geneva mines are respectively 1,400 and 1,700 ppm.

Origin of intercepted groundwater. These data suggest that groundwater intercepted at the Sunnyside and Geneva mines is the result of deep percolation from surface precipitation. The pattern of discharge from both mines follows the natural hydrologic cycle in that interception increases during the snowmelt season. Water intercepted from perched aquifers would not be expected to follow this seasonal pattern. Strong vertical cracking, in some cases reaching the surface, and steeply dipping faults encourage vertical percolation. The average TDS levels of 1,400 and 1,700 ppm also suggest that the water has traveled through the salt laden formations above the mine. Finally, the low annual precipitation in the area would not likely produce a regionally continuous groundwater table.

Future groundwater interception. Interception of groundwater in the future should remain constant at approximately 2.6 inches per year. Therefore, groundwater discharge should increase about 0.13 gallons per minute for every acre of future underground development.

Utah No. 2 mine

Geographic and geologic setting. The portal of the Utah No. 2 mine is located in section 8 of Township 13 South and Range 7 East at an elevation of 8,040 feet (see Figure 2.4). The mine has been worked eastward into the Blackhawk formation at approximately 6 degrees downdip. The region is located in the Pleasant Valley fault zone, a major north-south trending system extending from the Price River in the north to Cottonwood Creek in the south (Doelling 1972). The mine itself is crossed by two or three east-west trending faults (personal communication, confidential source).

Hydrologic setting. Normal annual precipitation in the area is about 18 inches (Jeppson et al. 1968). Pleasant Valley Creek, a perennial stream feeding Scofield Reservoir 4 miles to the north, is at an

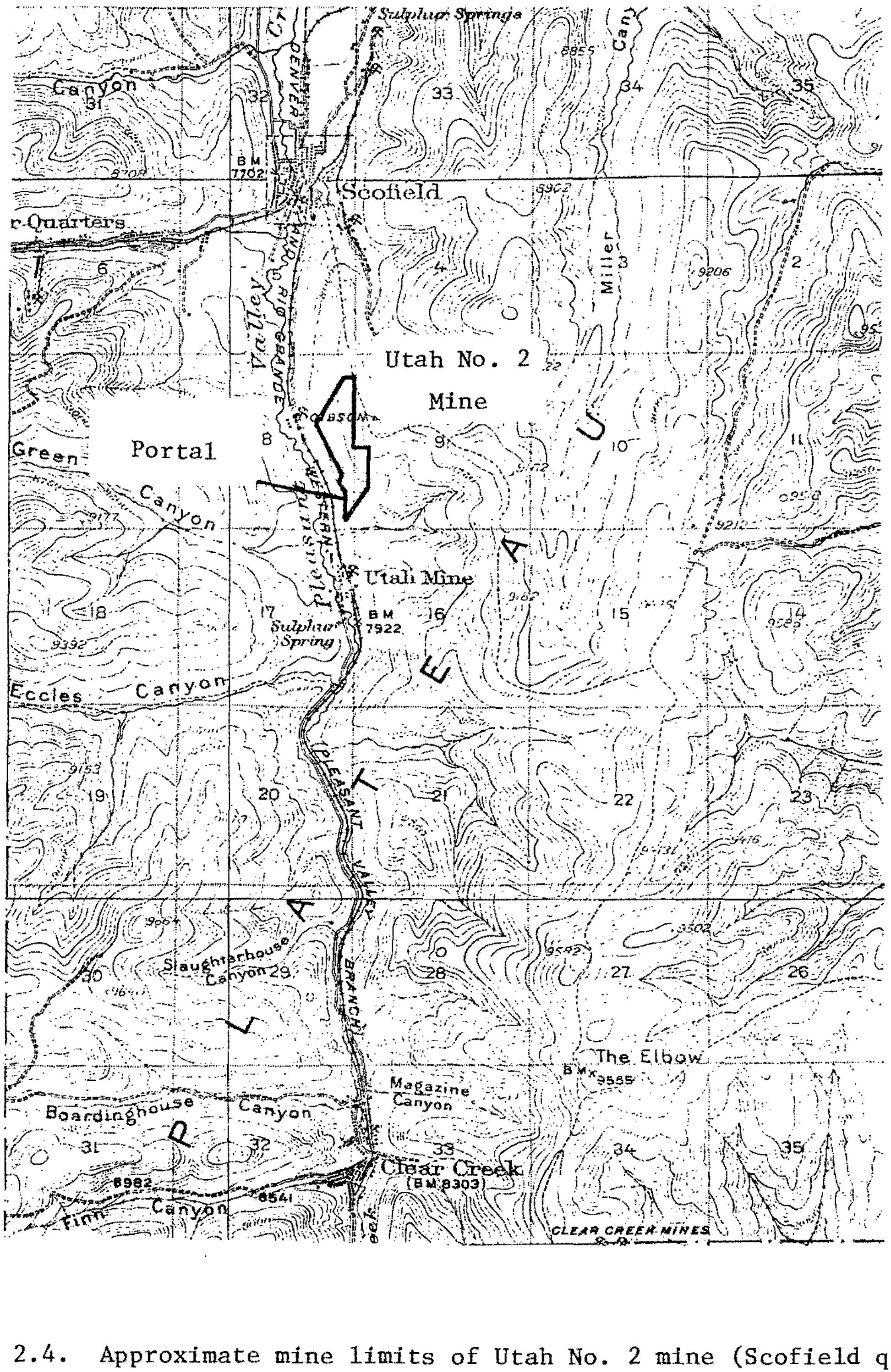


Figure 2.4. Approximate mine limits of Utah No. 2 mine (Scofield quadrangle from U.S. Geological Survey).

elevation of approximately 7,850 feet as it flows approximately 1/2 mile west of the mine. A water table is thought to exist on the west side of the valley opposite the Utah No. 2 mine (see Figure 2.5).

Intercepted groundwater. The Utah No. 2 mine discharged intercepted groundwater at an average rate of 450 gallons per minute when it closed in July of 1978. This amounts to an equivalent depth of 113 inches per year over the mined out acreage. Interception was described to be greatest near the working face of the mine where coal was being extracted. Mined out areas quickly dried up (personal communication, confidential source).

After mining commenced in 1974, a spring at elevation 8,000 feet and 1 1/2 miles north of the mine portal went dry. Two wells 140 feet deep at the mine portal also went dry as mining continued. Since mine closure in July of 1978 the spring has again commenced to flow. No information was available describing recent elevations of water in the wells.

Origin of groundwater. Based on available information, the Utah No. 2 mine appears to have tapped a significant aquifer. The annual interception rate of 113 inches precludes the possibility of groundwater being the result of deep percolation from surface precipitation alone. The fact that a spring and two wells dried up as mining proceeded downdip into the mountain and that interception was greatest at the working face of the mine strongly suggests that the mine intercepted a water table.

Future groundwater interception. If mining were to continue deeper into the aquifer, groundwater would probably continue to be intercepted. The water would come from continued drainage of the aquifers, from Pleasant Valley Creek as it is changed from an effluent to an influent stream, and from deep percolation over the mine. The volume of interception should slowly decrease with time as the aquifer is drained and steady state conditions are approached.

Belina No. 1 mine

Geographic and geologic setting. The portal of the Belina No. 1 mine is located in section 30 of Township 13 South and Range 7 East at an elevation of 9,035 feet (see Figure 2.6). The mine, which commenced operations in November of 1977, extracts coal from the Upper O'Connor bed of the Blackhawk formation under 400 feet of overburden (personal communication, confidential source and U.S. Geological Survey 1978e). Mining proceeds downdip at approximately 5 degrees and terminates at the intersection of the north-south trending Conneville fault, which drops the coal bed approximately 200 feet.

Hydrologic setting. Normal annual precipitation over the mining area is 27

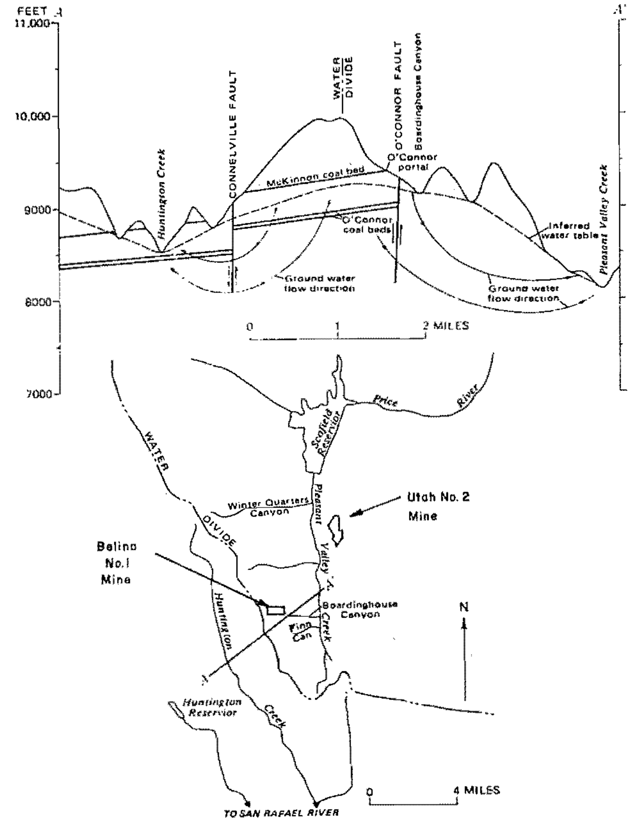


Figure 2.5. Section and map through O'Conner lease area, showing probable groundwater flow. Coal beds assumed dip at 5° NW (base map from U.S. Geological Survey 1978e, p. 20-23).

inches; and average annual water yield, or water which appears as surface runoff in springs and streams, is about 12 inches (Jeppson et al. 1968). A water table is thought to exist below the mine (see Figure 2.5), and 1/2 mile to the south is thought to be approximately 725 feet below the ground surface.

Intercepted groundwater. Groundwater intercepted at the Belina No. 1 mine is the equivalent of 5.6 inches per year over the 21.6 mined acres. During preparation for mining, several holes were drilled in the area, but no continuous source of water was found above the coal beds. Water intercepted in the mine flows primarily from the roof and is seen to decrease with time (personal communication, confidential source).

The absence of a continuous source of water from drill holes over the mining area indicates the absence of a regional groundwater table above the mine. Based on available information, groundwater intercepted at the Belina No. 1 mine appears to originate from perched aquifers and deep percolation of surface precipitation. Flows of water entering the mine decrease with time, imply-

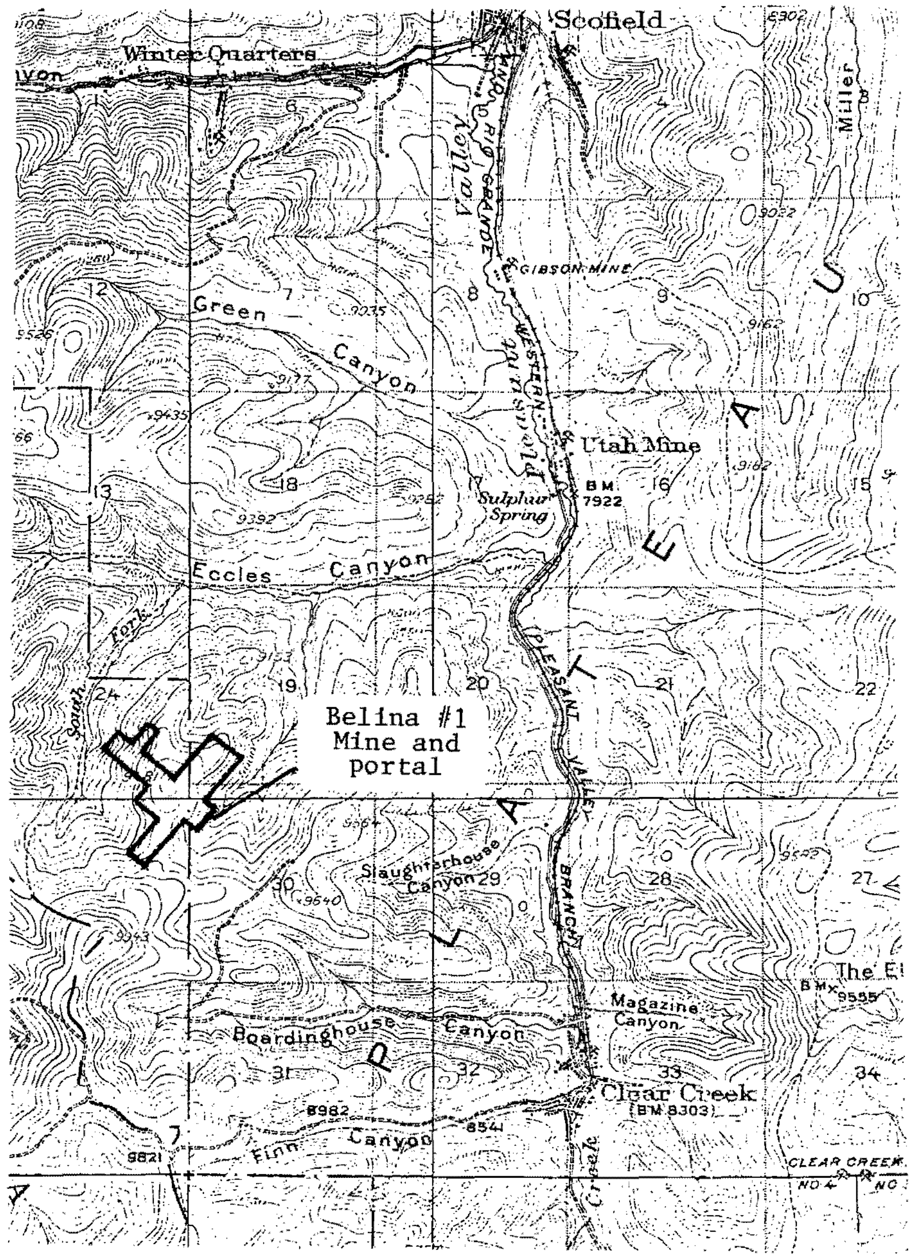


Figure 2.6. Approximate mine limits of Belina No. 1 mine (Scofield quadrangle from U.S. Geological Survey).

ing that the mine drains perched aquifers. The small mined acreage (21.6 acres) and short development life (2 years) of the mine also suggest that previously undrained perched aquifers are being encountered. The shallow overburden of 400 feet, cracked by the mining process, enhances vertical percolation of surface precipitation. These two components, the initial drainage of perched aquifers and the continuing contribution from surface precipitation, could well account for the 5.6 inches of groundwater annually intercepted at the mine.

Future groundwater interception. Since mining ceases at the Conneville fault, interception of a regional groundwater table, if one exists, is not likely. Considering the relatively small overburden volume above the mine, the future contribution of perched aquifers to the mine will probably decrease. Within a few years an equilibrium condition should evolve between deep percolation and groundwater interception. While exact numbers are unknown, due to the relatively high annual yield (12 inches) and shallow overburden (400 feet), an annual interception of 4 inches is not inconceivable. If true, mining would then intercept groundwater at a rate of approximately 4.5 gallons per minute per acre of development.

Hiawatha complex

Geographic and geologic setting. The Hiawatha coal mine, known by several names throughout its 89 year history, is located in Townships 15 and 16 South and Ranges 7 and 8 East (see Figure 2.7). Coal is extracted from the slightly southeasterly dipping Blackhawk formation approximately 1,000 feet below the ground surface. The mine is bound on its western edge by the north-south trending Bear Canyon fault. Mining has proceeded in a northwest direction from the Mohrland portal.

Hydrologic setting. Normal annual precipitation in the area is approximately 16 inches. Cedar Creek and Miller Creek are two perennial streams flowing over the mined out area. An average annual streamflow hydrograph for Cedar Creek over the period from 1973 to 1978 is shown in Figure 2.8.

Groundwater interception. Groundwater interception at the Hiawatha mine averages 850 gallons per minute throughout the year, or an equivalent average annual intercepted depth of 2.8 inches over the mined out area. Water enters the mine primarily from the Bear Canyon fault and flows southeasterly through the mine to its point of discharge at the abandoned Mohrland portal (see outflow hydrograph in Figure 2.8). Old mine workings have contacted the fault at several places and account for the majority of the discharged minewater. Small volumes of water enter through the floor and roof in the form of drippers or small steady trickles. These sources usually dry up as development progresses (personal communication, confidential source).

Origin of groundwater. Based on available data, the groundwater intercepted at the Hiawatha mine appears to be primarily the result of deep percolation from surface precipitation. The annual peak in the mine discharge hydrograph at the beginning of June coincides with the annual peak of the overlying Cedar Creek and is probably the result of snowmelt percolation into the southerly abandoned areas of the mine near the Mohrland portal. The lower January peak is probably the result of the previous spring's snowmelt percolation in the northwest region of the mine, 5 miles from the Mohrland portal and under approximately 1,500 feet of overburden. Deep percolation is likely conducted along cracks and geologic interfaces to the Bear Canyon fault where it percolates vertically and is intercepted by the mine.

The fact that some water enters the mine and decreases in volume suggests that perched aquifers are also being drained, but the overall effect is not seen on the discharge hydrograph and the contribution to the total discharge volume is probably small.

Future groundwater interception. Because most of the groundwater intercepted by the Hiawatha mine originates in the abandoned section of the mine and along the Bear Canyon fault in the active portion of the mine, groundwater interception should not significantly increase in the future. As mining continues, new sources of groundwater will likely be small unless extensive contact with the Bear Canyon fault is maintained. In the future, therefore, mine discharge should continue to average 850 gallons per minute.

Wilberg and Deer Creek mines

Geographical and geological setting. The Wilberg and Deer Creek mines are located in sections 27 and 10, respectively, of Township 17 South and Range 7 East (see Figure 2.9). The mines extract coal from the Hiawatha coal seam in the Blackhawk formation between 7,000 and 8,000 feet above mean sea level. Strata dip gently to the west at about 5 degrees (Doelling 1972). A general area stratigraphic column (see Table 2.2) shows that the Blackhawk formation is underlain by the Starpoint sandstone and overlain by the Castlegate sandstone. Overburden averages 1,000 feet.

Both mines are intersected by the north-south trending Pleasant Valley fault. Two other similar faults separate the mines from the adjacent Church mines to the southeast. A gentle syncline striking southwest-northeast and dipping slightly to the southeast crosses the Township (see Figure 2.10).

Hydrologic setting. Normal annual precipitation over the area is 20 inches (Jeppson et al. 1968). Intermountain Consultants and Planners (1977a) stated that the

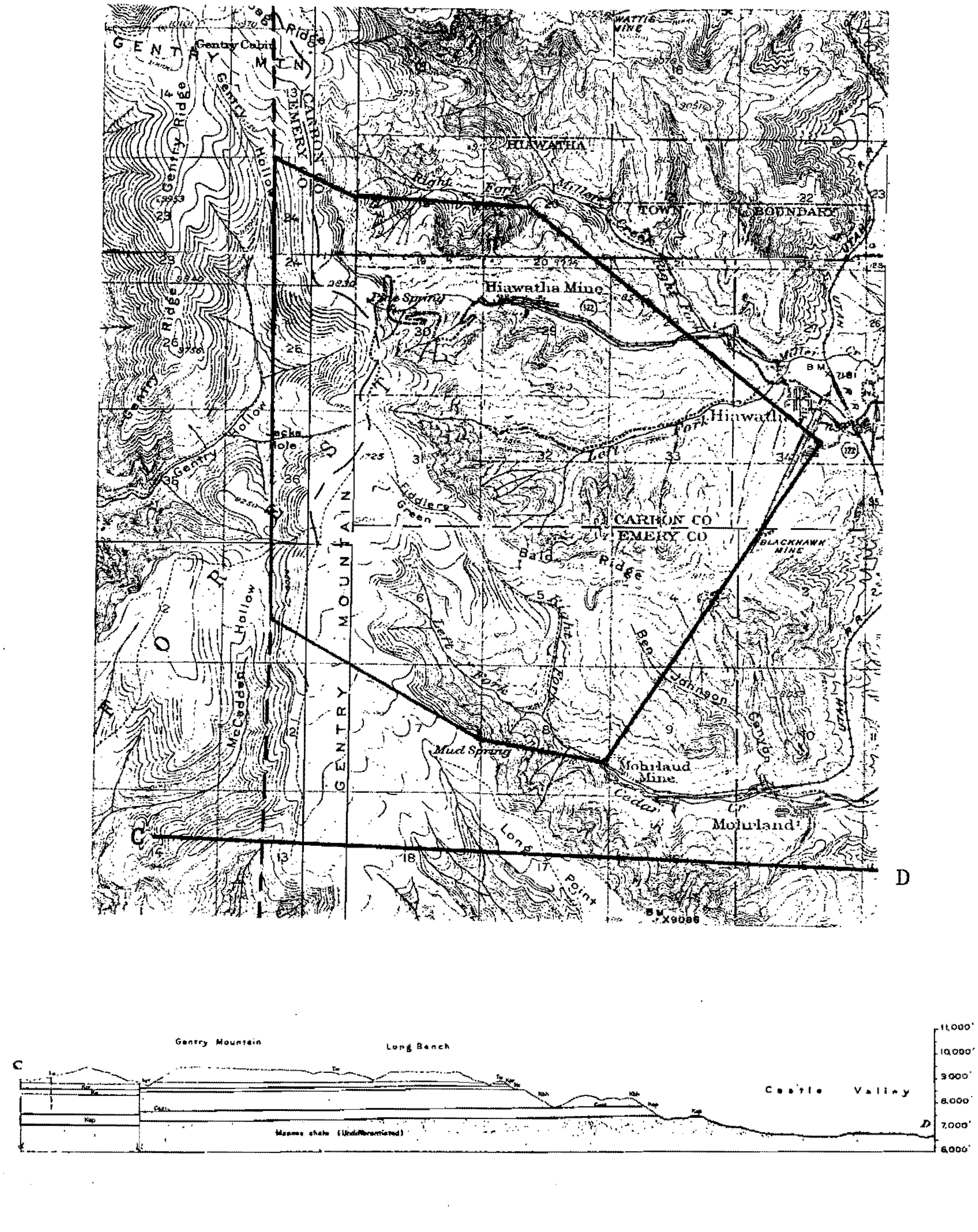


Figure 2.7. Approximate developed area of Hiawatha mine showing Bear Canyon fault (dotted line) (Scofield quadrangle from U.S. Geological Survey and cross section taken from Spieker 1931).

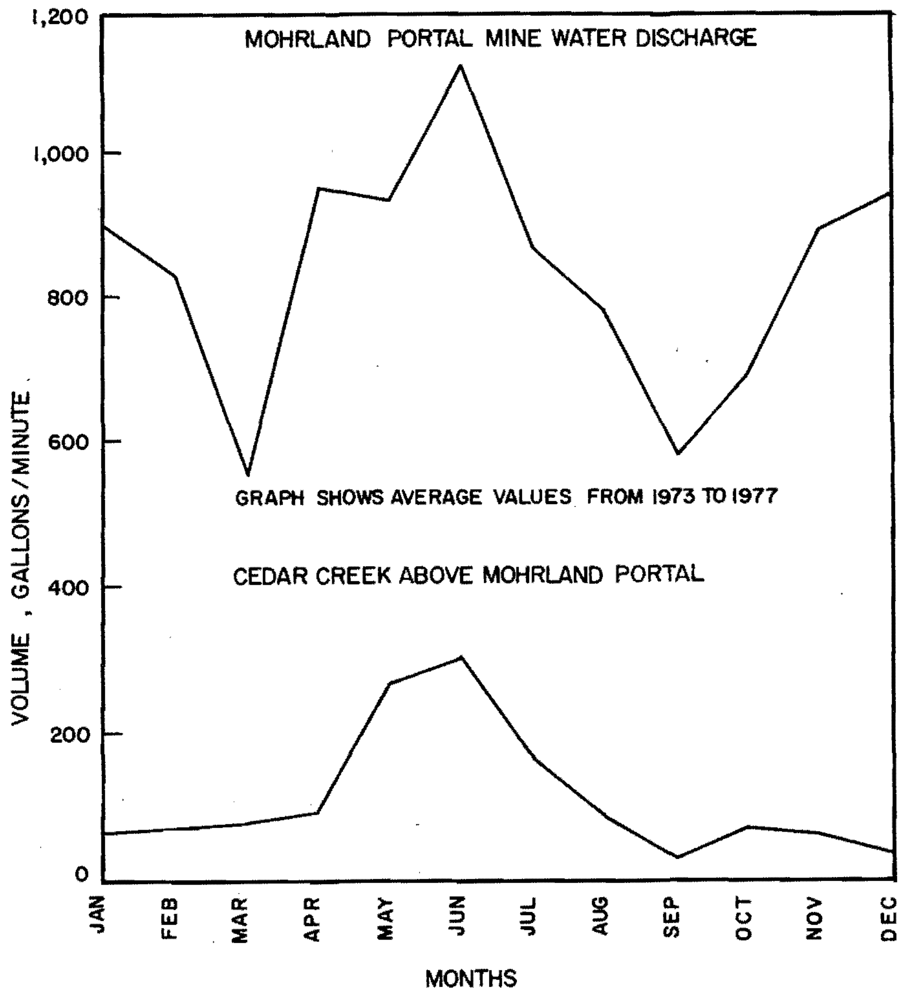


Figure 2.8. Average annual hydrographs (1973-1978) for Hiawatha mine at Mohrland portal and Cedar Creek above Mohrland portal (data from personal communication, confidential source).

Table 2.2. Geologic strata in study area (from Intermountain Consultants and Planners 1977a).

Formation	Thickness (feet)	Lithology
Flagstaff Limestone	650	Blue, gray, and white limestone; forms cliffs
North Horn Formation	1,000	Mostly variegated shale, some limestone, sandstone and conglomerate
Price River Formation	600	Sandstone, conglomerate, some shale
Castlegate Sandstone	200	Massive sandstone, weathering gray to buff, some conglomerate
Blackhawk Formation	750	Sandstone, siltstone, shale or claystone and coal
Star Point Sandstone	450	Massive Sandstone, buff to gray

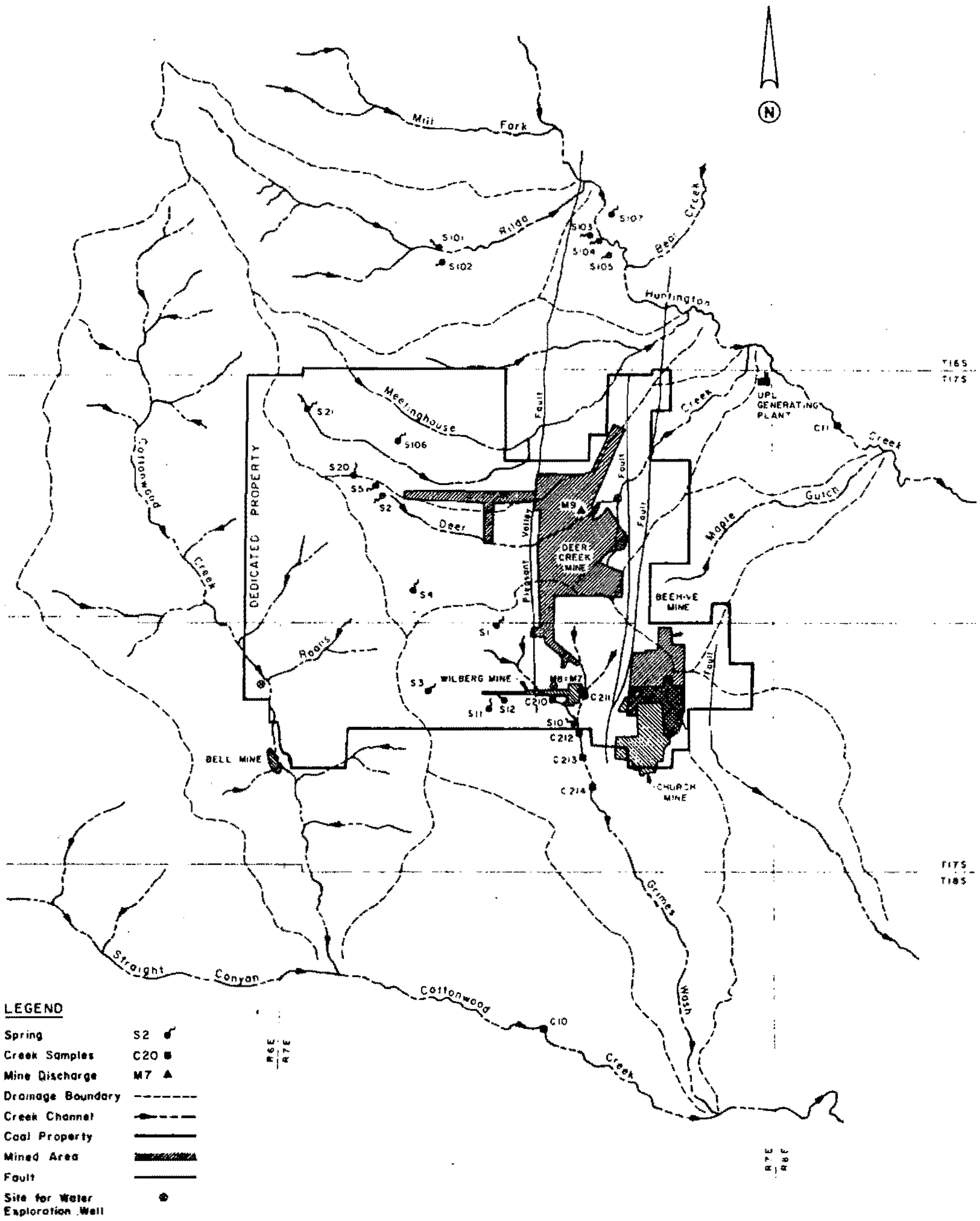


Figure 2.9. Approximate locations of Deer Creek and Wilberg mines, Utah.

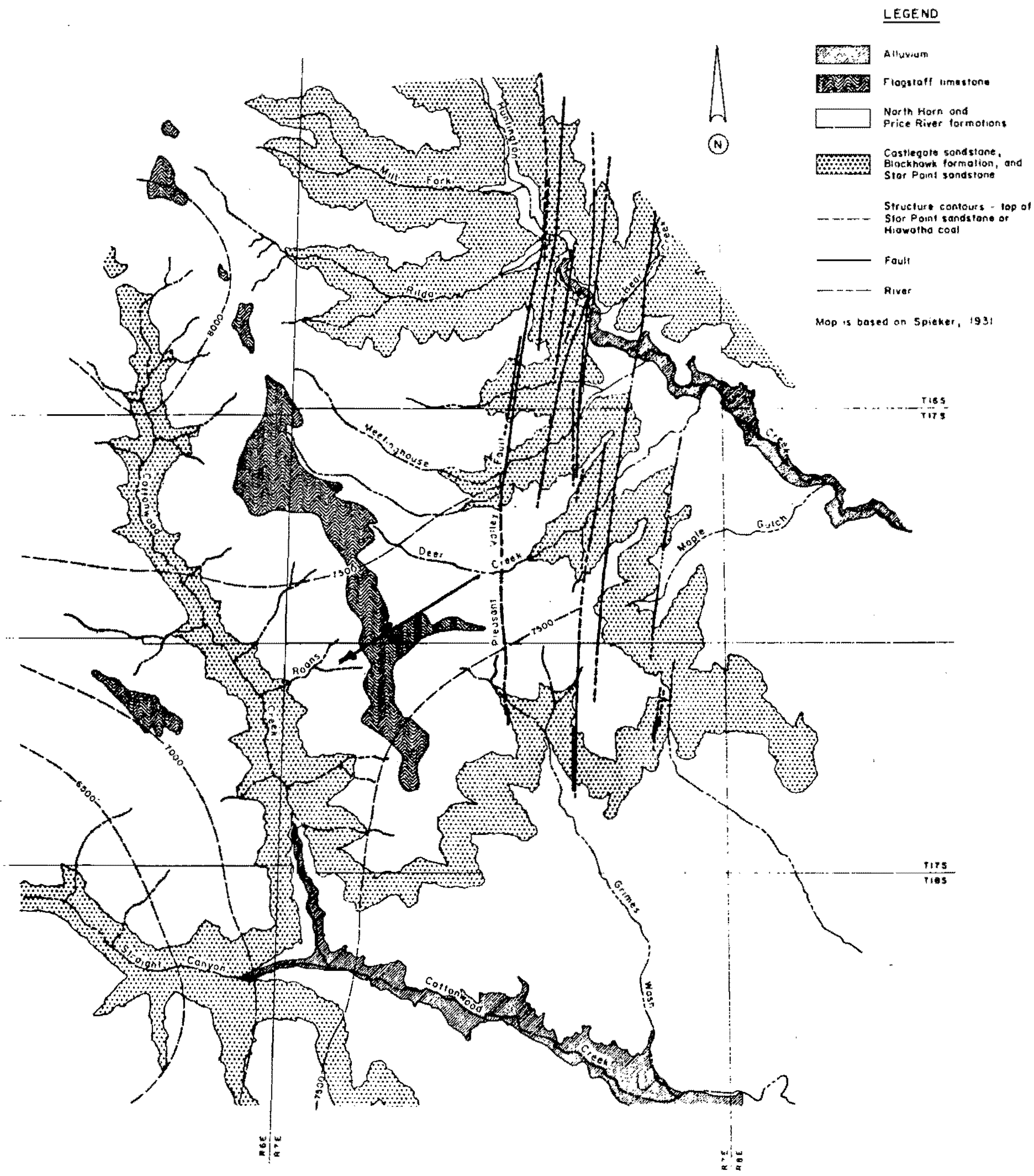


Figure 2.10. Geological map of Deer Creek and Wilberg mine area.

mean annual water yield, the difference between precipitation and evapotranspiration, is from 3 to 4 inches. Several streams divide the mining area into four small watersheds. Springs are found above the mines to the west. No surface springs were found below the Deer Creek mine, while one spring flows from a point lower than the Wilberg portal.

Concerning groundwater, Intermountain Consultants and Planners (1977a) states:

> Recharge to the subsurface water in East Mountain must come primarily from deep percolation of snowmelt and rain on the mountain. Some of this groundwater migrates toward the south end of East Mountain, where it either reappears at some point on the land surface (as springs or as base flow in the deep canyons which incise the mountain slopes), or percolates downward through fractures in the rock to deeper underlying formations. In either case, the zone of faulting shown by Figure 1 [Figure 2.10] seems to have a major influence on the migratory pattern of the underground waters of East Mountain. The occurrence of water in the mines and on the surface suggest that the fault zone appears to impede the horizontal component of groundwater flow in a southeasterly direction within East Mountain. For example, both the Church and Beehive mines lying east of the fault zone (Figure 1) [Figure 2.10] are essentially dry (p. 4).

When discussing the quantity of groundwater flow, the report continues:

> Although the average water yield over the mountain (that contributing to runoff and deep percolation) is approximately three to four inches, in detail this yield is closely related to altitude, so that yield is greater on the west side of the Township, beneath the 9,000 foot-plus ridge, than it is on the east side of the Township, beneath the lower portions of the mountain (p. 25).

In a more recent study of the same area, Intermountain Consultants and Planners (1977b) concludes:

> ... no indication of the existence of a continuous groundwater aquifer overlying the coal beds was found in any of the (18) drill holes. These findings support the proposition that if there is a zone of complete saturation, it is likely well below the deepest part of the coal beds under East Mountain (p. 8).

Intercepted groundwater. The Wilberg and Deer Creek mines intercept the equivalent of 10 to 16 inches and 3.2 inches of water, respectively. Water drains into the mines through bolt holes drilled in the roof. Mine personnel report that the rate of flow from the bolt holes in the Wilberg mine appears to diminish with time after they are drilled (Intermountain Consultants and Planners 1977a). Inflow hydrographs from many holes support this statement (Figure 2.11), but some holes have discharged groundwater at a nearly constant rate for the two month period of March and April 1977.

Origin of groundwater. Based on available data, it appears that groundwater intercepted in the Wilberg mine is primarily from perched aquifers, while groundwater entering the Deer Creek mine comes primarily from deep percolation of surface precipitation. Quantities of water intercepted at the Wilberg mine exceed annual water yield in the area, suggesting that other sources must be contributing water to the mine. The time pattern of mine inflow, coupled with the fact that no continuous groundwater table exists over the mine, suggests that perched aquifers must contribute significantly to mine interception of groundwater. The short coal production history (less than five years) also supports this statement because groundwater equilibrium conditions probably have not been reached.

The Deer Creek mine has been in operation for 28 years. Any perched aquifers over the mine have probably long since drained. The interception rate of 3.2 inches per year lies well within the range of possible deep percolation.

Future groundwater interception. The Wilberg and Deer Creek mines seem to represent non-steady state and steady state conditions, respectively, in groundwater interception. The Deer Creek mine should continue to intercept groundwater at an approximate rate of 3.2 inches per year. Discharge should increase by approximately 250 gallons per day per acre of new development. Groundwater interception by the Wilberg mine should decrease as perched aquifers drain. Its steady state interception of groundwater is expected to be higher than that by Deer Creek because it probably intercepts groundwater that might otherwise be bound for the Church mines to the southeast. Based on the size of the Church mines, an annual steady state interception rate of 5 inches per year at the Wilberg mine is estimated.

Gordon Creek No. 3 mine

Geographical and geological setting. The portal of the Gordon Creek No. 3 mine is located in section 16 of Township 13 South and Range 8 East at an elevation of 7,564 feet. The mine, operating since 1975, extracts coal from the Hiawatha seam of the Blackhawk formation at a dip of 3 degrees

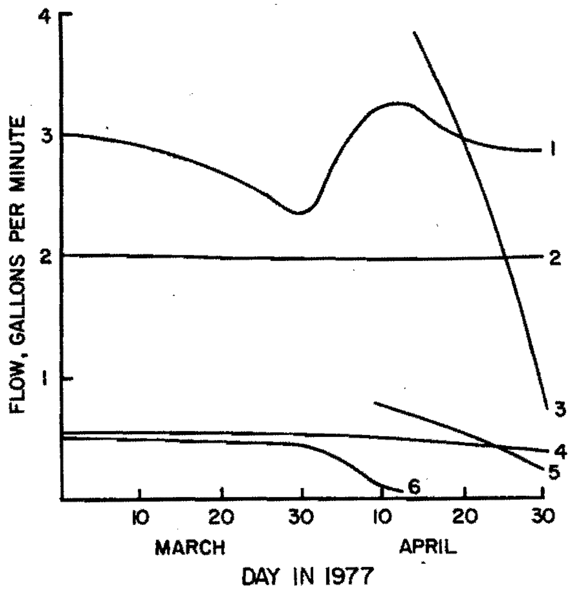


Figure 2.11. Inflow hydrographs from six roof holes in Wilberg mine (data from Intermountain Consultants and Planners 1977b).

downward under an average overburden of 700 feet. Major faults intersecting the mine (Figure 2.12) trend North 40 degrees West. Two other mines, the Gordon Creek No. 2 and No. 6 mines, operate in the same area. The three mines are compared in Table 2.3.

Hydrologic setting. Normal annual precipitation over the mining area is 21 inches and mean annual yield is approximately 4 inches (Jeppson et al. 1968). No information is currently available concerning springs or streamflow.

Intercepted groundwater. The Gordon Creek No. 3 mine intercepted groundwater at an average annual equivalent depth of 109 inches in 1977 and 31 inches in 1978. The No. 6 mine, almost immediately above the No. 3 mine and opened in August of 1978, has not intercepted groundwater to date. The No. 2 mine has recently begun to intercept groundwater in its 360-acre, 11-year old development (personal communication, confidential source).

Origin of groundwater. The origin of the water intercepted by these mines is uncertain. It is evident that the volume of groundwater intercepted at the No. 3 mine cannot be the result of deep percolation from surface precipitation alone. The decreasing rate of interception suggests that either a groundwater table is being lowered or perched aquifers are being drained. The No. 2 mine, for 10 years dry and just recently intercepting groundwater, may be intersecting a local groundwater aquifer.

Future intercepted water. It is difficult to predict the rate of groundwater interception in the future. Additional data are needed on:

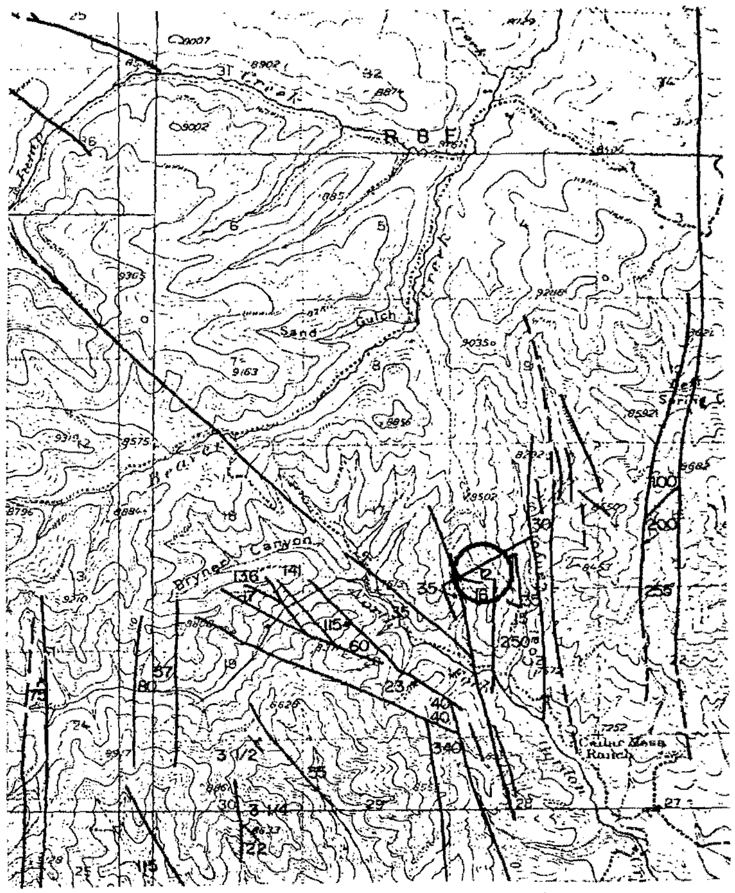
1. Location and discharge of any local springs.

2. Water levels in drill holes in the area.

3. More detailed discharge records from the mines.

Table 2.3. Comparison of Gordon Creek No.'s 2, 3, and 6 mines (information from personal communication, confidential source 1979).

Mine Name	Portal Location in T 13S., R. 8E.	Portal Elev. Feet	Coal Seam	Discharge Water?
Gordon Creek #3	SE1/4NE1/4SW1/4S.16	7564	Hiawatha	Yes
Gordon Creek #2	SW1/4NW1/4SE1/4S.18	7934	Castlegate "A"	Some
Gordon Creek #6	Sec. 16	7727	Castlegate "A"	No



Gordon Creek No. 3 Mine

/55 Fault and Displacement
in feet

Scale: 1:84,480

N ↑

Figure 2.12. Location of Gordon Creek No. 3 mine and local faults (taken from Doelling 1972, Vol. 3, p. 212).

CHAPTER III

THE POTENTIAL FOR USING UNDERGROUND COAL MINES TO REDUCE THE SALT LOAD TO THE COLORADO RIVER

It is the objective of this chapter to evaluate the potential for using underground coal mines in the Upper Colorado River Basin of Utah to reduce the salt load to the Colorado River. The Introduction treats the scope of the problem and develops the research objective. The Research Procedure delineates the steps taken to evaluate the objective, and the Results contain assembled data. The chapter concludes with a discussion of the results, a summary, and recommendations.

Introduction

Much concern has been expressed over the rising salinity level of the Colorado River. Annual downstream damages have been estimated to increase at a rate of $230,000 per milligram per liter of added salt (UWRL 1975).

Coal mines and salt load

This concern over salinity in the Colorado River requires identification and analysis to determine what can be done to reduce all its potential sources, including underground and surface coal mines. Public Law 92-500, part 2(a) (1972) states in part that there shall be no discharge of water from industry including coal mines except when the permittee demonstrates that practical technology for elimination of the discharge(s) is not available, in which case, salinity effluent limitations based upon the maximum practical salinity reduction shall be required. Hence, the law requires either total containment of discharged water or the "maximum practical salinity reduction" in water that cannot be totally contained.

The Colorado River Basin Salinity Control Forum (1977, p. A-2) further elaborates: "Salinity standards state that '... the objective for discharges shall be a no-salt return policy whenever practicable.'" Where a no-salt return policy is not practicable, or exceptions to the policy allow salt discharge, the applicant for a discharge permit is required to propose different methods to reduce salt discharge and to justify those selected. The goal is to maintain the salinity levels of the Lower Colorado River at or below the values shown in Table 3.1.

Table 3.1. Target total dissolved solids concentration levels of Lower Colorado River (data from Colorado River Basin Salinity Control Forum 1978).

TDS Target Levels of Lower Colorado River Based on 1972 Historic Measurements	
Colorado River	Target TDS Concentration (mg/l or ppm)
Below Hoover Dam	723
Below Parker Dam	747
At Imperial Dam	879

Using coal mines to decrease the salt load to the Colorado River

Groundwater at several locations in Utah flows through salt bearing formations and becomes highly saline or brackish (UWRL 1975). Underground coal mines are largely at elevations higher than the marine formations serving as salt sources but lower than high mountain areas where most runoff originates. If they intercept groundwater, they are likely to do so before salinization occurs. Intercepting groundwater upstream of the salt bearing strata, then, would protect the groundwater from further salinization. If there is a local demand, the groundwater may be put to beneficial use in the area. If intercepted groundwater is too saline for beneficial use, it may still carry less salt into the stream than if it were to continue to percolate downward through more salt bearing strata. Therefore, using underground coal mines to intercept groundwater may reduce the salt load to the Colorado River by reducing groundwater movement through salt bearing strata.

Research Procedure

In order to evaluate the potential for using underground coal mines to reduce the salt load to the Colorado River, it was necessary to:

1. Define the groundwater flow path from the coal mining areas to the Colorado River in terms of

   a. direction of flow
   b. time of travel

2. Define the present salinity level of the Colorado River in Utah.

3. Assemble appropriate water quality records from

a. mines
b. spring and wells
c. surface streams

Results

Define the groundwater flow path

The groundwater flow path from the central Utah coal fields to the Colorado River is made difficult to define by the lack of data to describe the complex area geology. Current conjectures are based on limited field data. Groundwater may flow out of the Colorado Basin, into a groundwater reservoir, or add to the Colorado River system.

Groundwater leaving the Colorado River Basin. If groundwater were to travel west under the Wasatch Plateau, it would leave the Colorado River Basin and enter the Sevier River Basin.

Water entering groundwater reservoirs. A groundwater reservoir acts like an underground bowl, collecting water until full, then spilling its contents into surrounding geologic strata or, if under pressure, escaping from the reservoir upward through faults or cracks. Groundwater in the Book Cliffs area is believed to exhibit this behavior (personal communication with Bryce Montgomery 1979). Most groundwater recharge from precipitation over the Book Cliffs is thought to follow northward dipping strata into the Uintah Basin (Price and Miller 1975) (see Figure 3.1). There it may be trapped in a reservoir or be discharged under pressure to surface springs. As the reservoir fills, groundwater would eventually spill southward into the Price River basin.

Groundwater flow path to Colorado River. Groundwater moving from the Wasatch Plateau-Book Cliffs area toward the Colorado River is inhibited by the San Rafael Swell. Preliminary reports (Hood and Danielson 1979 and Israelsen and Haws 1978) suggest that the flow path in the Navajo sandstone from the Wasatch Plateau is south along the west edge of the swell and south and west at its southern tip (see Figure 3.2). Flow from the Book Cliffs area through the same formation is thought to proceed west at the north extreme of the swell. Flow on the east side of the swell is not well defined due to insufficient data to define a very flat groundwater table. The Navajo sandstone is the most important water bearing formation in the region. Aquifers beneath the Navajo are thought to transport water along a similar path (Hanshaw et al. 1969).

Time of travel. Water collected by the U.S. Geological Survey (Danielson and Hood 1979) from the southern extreme of the San Rafael Swell was dated at 30,000 within ± 5,000 years. The water was taken from the Navajo sandstone in an area where the gradient was decreasing in the southwest direction. It was concluded that the water was representative of that which eventually contributes to the Colorado River.

Salinity of the Colorado River

The mean annual total TDS for four stations on the Colorado River are shown in Table 3.2. The four-station average for the water years of 1974 through 1977 is 839 ppm. This figure is 14 percent higher than the Hoover Dam target (Table 3.1). The TDS concentration of the Price River at Woodside is much higher.

Water quality data

Water quality data were assembled from coal mines and from surface and groundwater quality sampling points within the area shown in Figure 3.2. These data are presented in Tables 3.3 and 3.4. Notation for Utah geologic formations is explained in Table 3.5, while well location notation is explained in Figure 3.3. Regional groundwater quality data were restricted to wells sampled at elevations greater than 3,500 feet above mean sea level, the lowest elevation of the Colorado River in Utah. Below this elevation, it was assumed that groundwater would no longer contribute to the Colorado River.

Discussion of Results

Three perspectives were used in examining these data to evaluate the potential for using underground coal mines to reduce the salt load input to the Colorado River. First, the groundwater data were examined on a regional basis, and this was followed by seven cases where data were sufficient to do mine-specific analyses. Finally, the remaining mine-related data are examined.

Regional groundwater

Table 3.3 shows that in all but a few cases regional groundwater TDS concentrations far exceed the TDS levels of the Colorado River. It may be concluded, therefore, that if water not intercepted by underground mines travels to the Colorado River via the aquifers shown in Table 3.3, the net effect will be an increase in the TDS concentration of the Colorado River.

Site specific studies

Sufficient water quality records were available at seven mine sites for site specific analyses. Discussions of the impacts of each underground mine on the salinity level of the Colorado River follow.

Utah No. 2 mine. The Utah No. 2 mine is located in sections 8 and 9 of Township 13 South and Range 7 East. TDS concentrations of waters in and around the mine are shown in

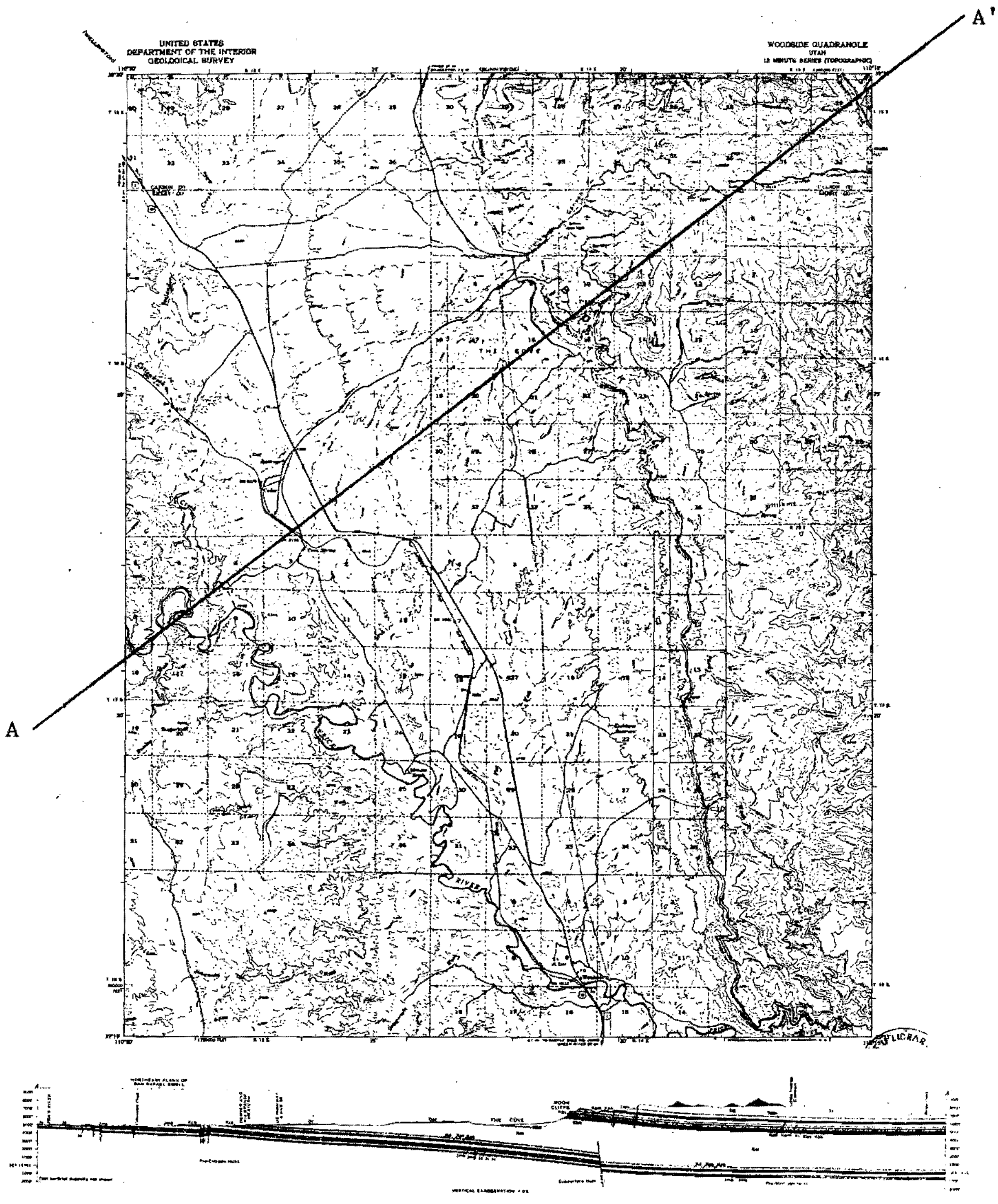


Figure 3.1. Northwesterly cross section through Woodside quadrangle (map from U.S. Geological Survey; cross section from Osterwald and Maberry 1974).

Table 3.2. Salinity of the Colorado River in Utah, water years 1974-1977 in ppm of TDS. Source: Water Resources Data for Colorado and Utah 1974-1977.

Station	Location	1974	1975	1976	1977[a]	Average
Colorado River below Colorado-Utah state line	Lat. 39° 05'18"N. Long. 109° 06'01"W.	743	692	785	1023	811
Colorado River near Cisco, Utah	Lat. 38° 48'38"N. Long. 109° 17'34"W.	798	762	812	1135	877
Colorado River near Moab, Utah	Lat. 38° 36'14"N. Long. 109° 34'38"W.	630	708	823	1127	822
Colorado River above Mill Creek, near Moab, Utah	Lat. 38° 34'31"N.	695	713	831	1138	844
			Colorado River average			839
Price River at Woodside, Utah	Lat. 39° 15'56" Long. 110° 34'41"	2880	2420	3325	4000	3156

[a]High 1977 salinities are probably more indicative of severe drought conditions than of time trends.

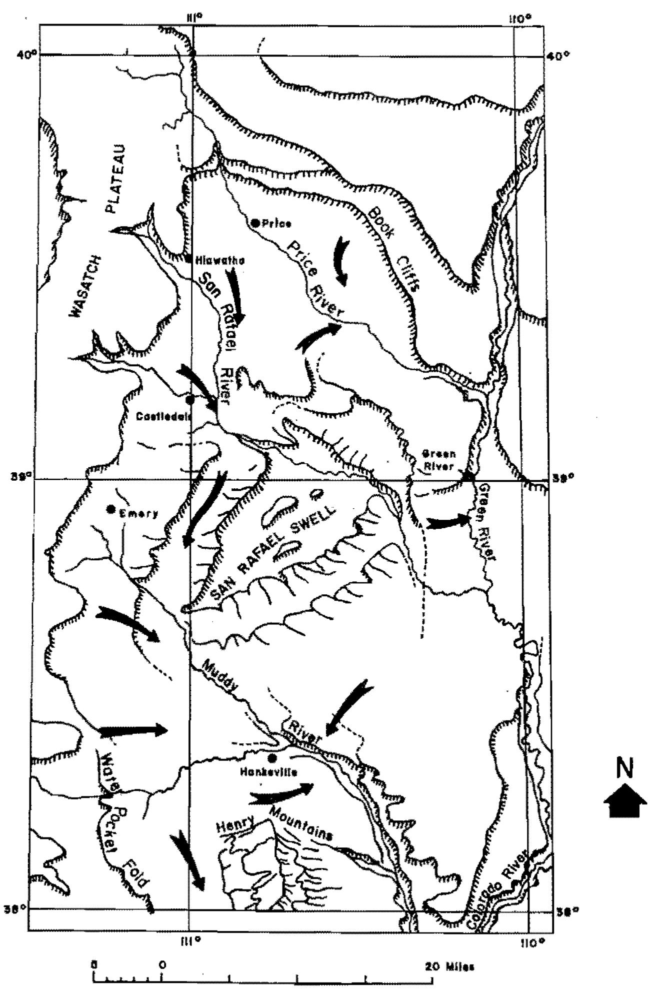


Figure 3.2. Theorized groundwater flow path from central Utah coal fields to Colorado River (base map taken from U. S. Geological Survey 1978e).

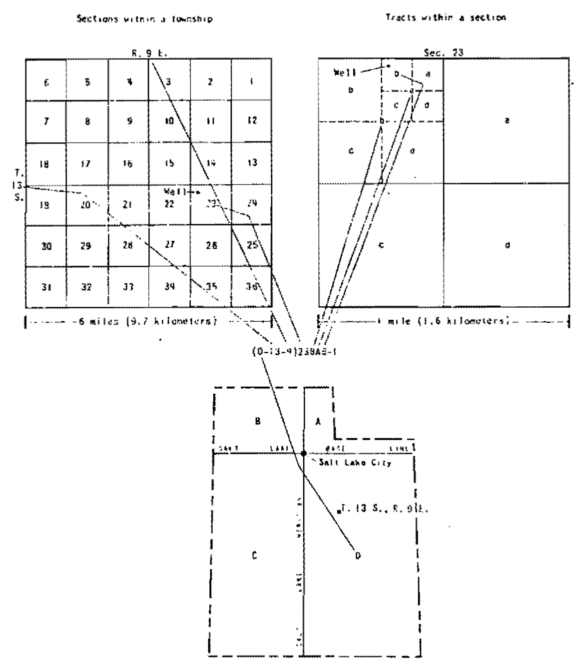


Figure 3.3. Well and spring numbering system used in Utah (taken from Waddell 1978, p. 3).

Table 3.3. Total dissolved solids in ppm of selected wells in Utah (Feltis 1966).

Location	Approx. Elev., feet	Type	Formation	Depth Feet	TDS ppm
T.26S., R. 7E., Sec. 20 C NE 1/4 SE 1/4	6,000	Oil	220 NVJO[a]	625	320
			231 WNGT	1,450	4,100
			231 CHNL	1,650	20,800
T.13S., R. 7E., Sec. 15 C SE 1/4 SW 1/4	9,000	Oil	211 FRRN	4,000	1,150
T.13S., R. 7E., Sec. 29 SE 1/4 SW 1/4 NW 1/4	9,000	Oil	211 FRRN	4,500	4,250
T.13S., R. 7E., Sec. 32 NW 1/4 SW 1/4 SW 1/4	9,000	Oil	211 FRRN	4,800	1,000
T. 13S., R. 7E., Sec. 32 SE 1/4 NW 1/4 SE 1/4	9,000	Oil	211 FRRN	4,200	630
T.14S., R. 7E., Sec. 5 E 1/2 SE 1/4 SW 1/4	9,000	Oil	211 FRRN	4,500	4,440
T.14S., R. 7E., Sec. 19 NW 1/4 SE 1/4 SW 1/4	9,000	Oil	211 FRRN	4,200	3,130
T.14S., R. 7E., Sec. 30 SE 1/4 NE 1/4 SW 1/4	9,000	Oil	211 FRRN	3,800	2,900
T.14S., R. 7E., Sec. 32 SE 1/4 NW 1/4 SW 1/4	9,000	Oil	200 MNCS	4,550	390
T.14S., R. 9E., Sec. 29	6,500	Oil	211 FRRN	2,700	52,000
			211 FRRN	2,800	37,000
			211 TNNK	3,000	11,000
T.15S., R. 12E., Sec. 15	5,500	Water	200 MNCS	30	6,280
T.20S., R. 7E., Sec. 27 SW 1/4 NE 1/4 SW 1/4	5,900	Oil	211 FRRN	800	21,000
T.17S., R. 7E., Sec. 25 SW 1/4 SE 1/4 SE 1/4	8,000	Oil	211 FRRN	3,700	14,500
T.22S., R. 4E., Sec. 17 SE 1/4 NW 1/4 NW 1/4	8,000	Oil	211 BCKK	1,175	2,400
			211 MSUK	2,075	1,793
T.22S., R. 5E., Sec. 23 NE 1/4 SW 1/4 SE 1/4	6,000	Oil	211 FRRN	1,300	7,400
			211 FRRN	1,400	8,000
			211 FRRN	1,425	8,200
			211 FRRN	1,525	7,000
			211 FRRN	1,180	9,500

[a]See explanation in Table 3.5.

Table 3.4. Total dissolved solids concentrations of surface and groundwater in the vicinity of underground coal mines in central Utah.

Mine Name	Location[a] T	Location[a] R	Location[a] S	Location[b]	Description of Water Quality: Source	Elevation (ft)	Well Depth (ft)	Water Level Above (+) or Below Datum	Principal[c] Aquifer	Date of Sample[d]	TDS ppm	Source of Data
Braztah Complex	13S	9E		394144 1105454	Stream	6350 (map)				18-09-75	1,700	Waddell (1978)
Sunnyside Complex	14S	14E	19	(D-14-14) 20DCC	Mine	6800			211 BCKK	1-07-76	1,280	Waddell (1978)
					Mine						1,520	Personal correspondence
											2,000	Brauer (1977)
				Outfall 001	Effluent					16-05-78	1,657	Div. of Health (1978)
				Outfall 001	Effluent					16-08-78	1,596	Div. of Health (1978)
				Outfall 001	Effluent					11-10-78	1,546	Div. of Health (1978)
				Outfall 002	Effluent					18-4-78	1,476	Div. of Health (1978)
				Outfall 002	Effluent					11-10-78	1,601	Div. of Health (1978)
				Outfall 003	Effluent					16-05-78	1,386	Div. of Health (1978)
				Outfall 003	Effluent					5-12-78	1,418	Div. of Health (1978)
				(D-14-14) 32DBB	Mine	6760			211 BCKK	18-03-53	601	USGS, Unpub.
				393608 1102247	Stream	7150 (map)				27-04-76	380	Waddell (1978)
										12-09-75	366	Waddell (1978)
										24-10-75	451	Waddell (1978)
Gordon Creek 3,6	13S	8E	7,17,18	Mine	Mine	8250 (map)				5-12-78	376	Personal correspondence
				Mine	Mine	8250 (map)				20-4-79	330	Personal correspondence
				Mine	Mine						590	Brauer (1977)
				Mine	Mine					18-04-78	424	Div. of Health (1978)
				Mine	Mine					16-05-78	364	Div. of Health (1978)
				Mine	Mine					15-08-78	414	Div. of Health (1978)
				Mine	Mine					11-10-78	312	Div. of Health (1978)
				Mine	Mine					5-12-78	376	Div. of Health (1978)
Geneva Complex	16S	14E		392712 1102224	Stream	6150 (map)				11-09-75	687	Waddell (1978)
				392712 1102224	Stream	6150 (map)				7-10-76	1,323	Waddell (1978)
					Mine	6300 (map)					2,244	Brauer (1977)
				Discharge 002	Mine					16-05-78	1,746	Div. of Health (1978)
				Discharge 002	Mine					16-08-78	1,766	Div. of Health (1978)
				Discharge 002	Mine					11-10-78	1,732	Div. of Health (1978)
				Discharge 002	Mine					5-12-78	1,784	Div. of Health (1978)
				(D-16-14) 4DBD	Well	6350 (map)	"Shallow"			13-09-78	1,765	Personal correspondence
				(D-16-14) 3ADA	Spring	6592				13-09-78	936	Personal correspondence
				(D-16-14) 3ADA	Spring	6550 (map)				13-09-78	920	Personal correspondence
				(D-15-14) 34CAB	Spring	6500 (map)				13-09-78	1,250	Personal correspondence
				(D-15-14) 34CBB	Spring	6450 (map)				13-09-78	1,230	Personal correspondence
				Above Mine	Stream					03-74	1,614	Personal correspondence
				Above Mine	Stream					10&11-76	901	Personal correspondence
				Above Mine	Stream						925	Personal correspondence
				Above Mine	Stream						938	Personal correspondence
				Above Mine	Stream						1,012	Personal correspondence
				Above Mine	Stream						3,113	Personal correspondence
				Above Mine	Stream						1,034	Personal correspondence
				Above Mine	Stream						1,052	Personal correspondence

Table 3.4. Continued.

Mine Name	Location[a] T	R	S	Location[b]	Source	Elevation (ft)	Well Depth (ft)	Water Level Above (+) or Below Datum	Principal[c] Aquifer	Date of Sample[d]	TDS ppm	Source of Data
					Description of Water Quality							
Hiawatha	15,16S	7,8E		(D-16-7) 1ACB	Spring	9625			125 NRHR	26-08-76	248	Waddell (1978)
				(D-15-7) 34BAB	Spring	9200			124 WSTC	19-08-76	325	Waddell (1978)
				(D-15-7) 12DEA	Spring	9650			125 NRHR	26-08-76	148	Waddell (1978)
				(D-16-8) 8DDA	Mine	7800			211 BCKK	18-09-75	671	Waddell (1978)
				(D-15-7) 35CBC	Spring	8010			211 BCKK	5-10-77	320	USGS, Unpub.
				(D-15-7) 35BDC	Spring	8504			211 CSLG	7-11-77	247	USGS, Unpub.
				(D-16-8) 8DAD	Mine	7720			211 BCKK	12-10-77	642	USGS, Unpub.
					Mine				211 BCKK		725	Personal correspondence
											725	Brauer (1977)
Belina No.1	13S	7E	30								286	Personal correspondence
Utah No. 2	13S	7E	8,9	(D-13-7) 8DAC	Mine	7890			211 MVRD	19-09-75	482	Waddell (1978)
				(D-13-7) 5CAB	Well	7900			211 BCKK	19-09-75	280	Waddell (1978)
				(D-13-7)BDAC-1	Well	7881	280	+105	211 BCKK	19-09-75	406	Waddell (1978)
				(D-13-7)8DAC-2	Well	7930	210	175.6	211 BCKK	19-09-75		Waddell (1978)
				(D-13-7) 17CDD	Spring	7950			211 SRPN	1-10-76	335	Waddell (1978)
				394125 1110913	Stream	7900 (map)				19-09-75	308	Waddell (1978)
					Mine						473	Personal correspondence
					Mine						574	Brauer (1977)
Emery Deep	22S	6E	28,29 32,33	(D-22-6) 29DDD	Mine Discharge	5960			211 FRRN	16-09-76	5,100	Waddell (1978)
				(D-22-6) 33BDC	Mine D.	6000			211 FRRN	23-01-53	3,454	Waddell (1978)
				(D-22-6) 17ABC	Well	6285	1,543	+48	211 FRRN	10-09-75	652	Waddell (1978)
				(D-22-6) 31DAB	Well	6030	406	+3.5	211 FRRN	7-10-76	1,230	Waddell (1978)
					Mine D.						4,970	Brauer (1977)
					Mine D.						4,970	Israelsen and Haws (1978)
				Above Mine	Quitchupah Creek					12-04-77	3,332	Div. of Health (1977)
										13-07-77	2,250	Div. of Health (1977)
										17-08-77	1,778	Div. of Health (1977)
										18-04-78	1,234	Div. of Health (1978)
				Consolidation Coal Outfall	Mine D.					17-08-77	4,648	Div. of Health (1977)
										8-11-77	6,790	Div. of Health (1977)
										17-05-78	3,256	Div. of Health (1978)
										6-12-78	3,782	Div. of Health (1978)
				Below Mine	Quitchupah Creek					12-04-77	4,236	Div. of Health (1977)
										17-08-77	3,510	Div. of Health (1977)
										6-12-78	1,230	Div. of Health (1978)
				(D-22-6) 28CAA	Well	6080 (map)		100	211 FRRN	29-01-76	688	Personal correspondence
				(D-22-6) 32CCA	Well	5965 (map)		+	211 FRRN	28-29-04-74	1,200	Personal correspondence
				(D-22-6) 32CDD	Well	5970 (map)		+	211 FRRN	1-8-05-74	1,500	Personal correspondence
				(D-23-6) 5BBA	Well	5995 (map)		+	211 FRRN	28-04-74	800	Personal correspondence
				(D-22-6) 32CAB	Well	5960 (map)		+	211 FRRN	14-15-05-74	1,010	Personal correspondence

Table 3.4. Continued.

Mine Name	Location[a] T	R	S	Location[b]	Source	Elevation (ft)	Well Depth (ft)	Water Level Above (+) or Below Datum	Principal[c] Aquifer	Date of Sample[d]	TDS ppm	Source of Data
						Description of Water Quality						
				(D-23-6) 6ABA	Well	6025 (map)		+	211 FRRN	12-13-06-74	1,000	Personal correspondence
				(D-23-6) 6AAA	Well	6000 (map)		+	211 FRRN	25-30-06-74	1,328	Personal correspondence
				(D-22-6) 32DBB	Well	5975 (map)		+	211 FRRN	11-13-05-74	720	Personal correspondence
				(D-22-6) 20ABC	Well	6040 (map)		+	211 FRRN	2-12-04-74	740	Personal correspondence
				(D-22-6) 30DBC	Well	6020 (map)		+	211 FRRN	14-15-05-74	980	Personal correspondence
Co-op	16S	7E	20	(D-16-7) 17CCB	Spring	7450			211 FCRV	18-08-76	296	Waddell (1978)
				(D-16-7) 9CBD	Spring	7700			211 SRPN	7-05-53	349	USGS, Unpub.
				(D-16-7) 21BBB	Spring	7484			211 SRPN	4-10-77	422	USGS, Unpub.
				(D-16-7) 29DBB	Spring	7608			211 SRPN	4-10-77	381	USGS, Unpub.
					Mine						710	Israelsen and Haws (1978)
Deer Creek	17S	7E	10	(D-17-7) 10DAD	Mine	7440			211 BCKK	29-06-77	550	USGS, Unpub.
				(D-17-7) 11BCD	Mine	7300			211 BCKK	15-03-76	636	Waddell (1978)
					Mine					04-76	420	ICP (1977a,b)
					Mine						800	Israelsen and Haws (1978)
				(D-17-7) 7ACC	Spring	9800				07-76	< 200	ICP (1977a,b)
				(D-17-7) 8BCC	Spring	9200				07-76	490	ICP (1977a,b)
				(D-17-7) 21ABB	Spring	9250				07-76	450	ICP (1977a,b)
Wilberg Mine	17S	7E	27,34	(D-17-7) 21DCD	Spring	9100			125 NRHR	22-10-76	469	Waddell (1978)
				(D-17-7) 28BAD	Spring	9300			125 NRHR	22-10-76	332	Waddell (1978)
				(D-17-7) 27ABB	Mine	7300			211 BCKK	29-09-76	551	Waddell (1978)
				(D-17-7) 27ACA	Spring	7350			211 BCKK	29-09-76	750	Waddell (1978)
					Mine						730	Brauer (1977)
					Mine						612	Israelsen and Haws (1978)
					Mine Inflow						470	ICP (1977a,b)
					Mine Outflow						498	ICP (1977a,b)
				(D-17-7) 27ABB	Mine				211 BCKK	30-03-77	434	USGS, Unpub.
				(D-17-7) 27ABB	Mine Floor				211 SRPN	4-05-77	572	USGS, Unpub.
				(D-17-7) 27ABB					211 BCKK	11-01-77	481	USGS, Unpub.
				391754 1110630	Grimes Wash	6350 (map)				29-09-76	763	Waddell (1978)
				(D-17-7) 21ABB	Spring	9250				07-76	450	ICP (1977a,b)
				(D-17-7) 20DCA	Spring	9400				07-76	500	ICP (1977a,b)
Thompson	20S	20E	16	(D-20-20) 28BBB	Spring	5760			211 BCKK	10-10-76	693	Waddell (1978)
				(D-20-20) 21BCC	Spring	5900			211 FRRN	8-10-76	798	USGS, Unpub.
Knight	23S	4E	34	(D-23-4) 36BAD	Spring	7040			211 SRPN	16-09-76	391	Waddell (1978)
				(D-23-4) 34CAB	Well	7720 (map)	595	845	211 SRPN	1-09-78	793	USGS, Unpub.
				(D-23-4) 16BAB	Spring	8080			211 BCKK	16-09-76	230	USGS, Unpub.
				(D-23-4) 21ADD	Spring	8160			211 BCKK	16-19-76	355	USGS, Unpub.
				(D-23-4) 34CDA	Mine				211 BCKK	1-09-78	1,700	USGS, Unpub.
Convulsion Canyon	22S	4E	12	(D-21-4) 34BCD	Spring	8200			211 PCRV	16-09-76	786	Waddell (1978)
				(D-22-4) 12BDA	Mine	7600			211 BCKK	27-09-76	276	Waddell (1978)
				(D-22-4) 24BAC	Spring	8320			211 PCRV	17-09-76	122	Waddell (1978)
				(D-22-4) 12BDB	Mine	7550			211 BCKK	1-09-78	368	USGS, Unpub.
				385422 1112434	Stream	7000 (map)				27-09-76	421	Waddell (1978)

[a]Referenced as Township, Range, and Section.

[b]Letter and number location refer to Utah well and spring numbering system. See Figure for explanation. Number location is latitude north (degrees, minutes, seconds) and longitude west (degrees, minutes, seconds).

[c]See Table for explanation.

[d]Day, month, year.

Table 3.5. Notation for geologic formations in Utah.

EOCENE		
Wasatch Formation (Eocene-Paleocene)	124	WSTC
PALEOCENE		
North Horn Formation (Paleocene-Upper Cretaceous)	125	NRHR
MESOZOIC		
Mancos Shale	200	MNCS
UPPER CRETACEOUS		
Blackhawk Formation of Mesaverde Group	211	BCKK
Castlegate Sandstone of Mesaverde Group	211	CSLG
Ferron Sandstone Member of Mancos Shale	211	FRRN
Masuk Member of Mancos Shale	211	MSUK
Mesaverde Group	211	MVRD
Price River Formation of Mesaverde Group	211	PCRV
Star Point Sandstone of Mesaverde Group	211	SRPN
Tununk Shale Member of Mancos Shale	211	TNNK
Tuscher Formation of Mesaverde Group	211	TSCR
JURASSIC		
Navajo Sandstone of Glen Canyon Group (Jurassic-Triassic)	220	NVJO
UPPER TRIASSIC		
Chinle Formation	231	CHNL
Wingate Sandstone of Glen Canyon Group	231	WNGT

Figure 3.4. The well nearest the mine flows under artesian conditions. Water discharged from the mine has a TDS level very similar to that of the well and similar to other waters in the area. The mining operations, therefore, have a negligible effect on groundwater quality. Discharge water from the mine has a lower TDS level than the Colorado River and may be beneficially used in the area. Based on local topography and other information described in Chapter II, groundwater not intercepted by the mine would probably emerge as a surface spring or as groundwater contributing to Pleasant Valley Creek. No other data are available describing the TDS concentration of groundwater entering Pleasant Valley Creek, but probably most contributions are similar in quality to those of the wells and springs shown by Figure 3.4.

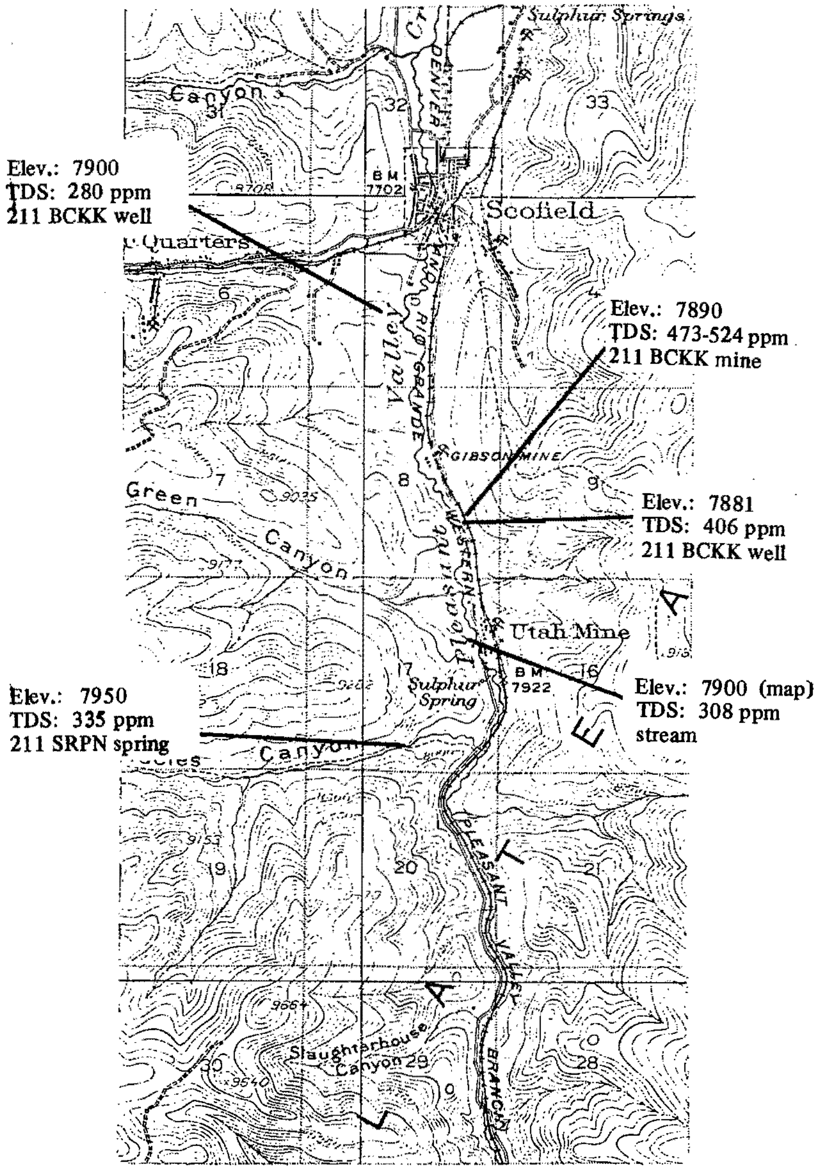
Sunnyside mine. The Sunnyside underground coal mine is located in Township 14 South and Range 14 East. The mine depth varies from 300 to 2,000 feet through alternating strata of sandstone and shale. The TDS concentrations for waters in the mine and surrounding area are shown in Figure 3.5. TDS levels, averaging 1,400 ppm, are very consistent throughout the 10-square mile mine. Whitmore Creek, flowing over the mine, originates from several springs emanating from beneath the shallow soil mantle in Whitmore Canyon and thus is not representative of groundwater intercepted by the mine. Springs feeding the north fork of Horse Canyon Creek, 8 miles to the south, more accurately reflect local groundwater conditions because they discharge water that has traveled through several hundred feet of strata. Horse Canyon Creek has TDS concentrations very similar (averaging 1,320 ppm) to those of the Sunnyside mine, and therefore, discharged minewater may be assumed to be representative of the area groundwater. Although the average TDS level of the minewater (1,400 ppm) is higher than the Colorado River base figure of 839 ppm, the discharged groundwater is used extensively in the Sunnyside area for surface irrigation. The mining operation itself has not been shown to increase the TDS of intercepted water.

If water were not intercepted by the mine, it would likely travel downdip to the Uintah Basin. If this is so, the mine changes the direction of groundwater flow from north to south by discharging intercepted groundwater into southward flowing Horse Canyon Creek. Although the final TDS level of water currently traveling northward is unknown, Price and Miller (1975) comment concerning groundwater in the southern Uintah Basin:

> The rate of groundwater movement is slow in most places because of the generally low permeability of the rocks through which the water moves. This slow rate of movement allows longer periods of contact between the water and the rock minerals and contributes to the consistently high concentration of dissolved solids in the water (p. 29).

If such groundwater were to spill back into the Price River Basin, the river TDS levels would increase significantly. For example, the TDS concentration of the Price River at Woodside, 18 miles to the south, is 3,156 ppm (see Table 3.2). Although no pertinent salinity data are currently available, groundwater entering the Price River Basin from the Sunnyside area is probably discharged into the Price River. The high TDS in the Price River at Woodside may be partially the result of diffuse inflows of saline groundwater from the Book Cliffs area. If such is the case, groundwater not intercepted by the mine is contributing significantly to the salt load of the Colorado River. Consequently, intercepting groundwater with TDS concentrations of 1,400 ppm from the Book Cliffs area and discharging it into surface streams could reduce the salt load to the Colorado River. Whether it actually would or not depends on how much salt would be picked up by the flow in the streams on the way to the river.

Geneva mine. The Geneva mine is located in Township 16 South and Range 14 East. TDS concentrations of waters in and around the mine area are shown in Figure 3.6. TDS



Utah No. 2 Mine   T. 13S., R. 7E., Sec. 17

Formation Key: 211 BCKK: Blackhawk Formation
211 SRPN: Starpoint Sandstone

Scale: 1:62,500

Figure 3.4. TDS concentrations of water in and around Utah No. 2 mine, Utah (Scofield quadrangle from U.S. Geological Survey).

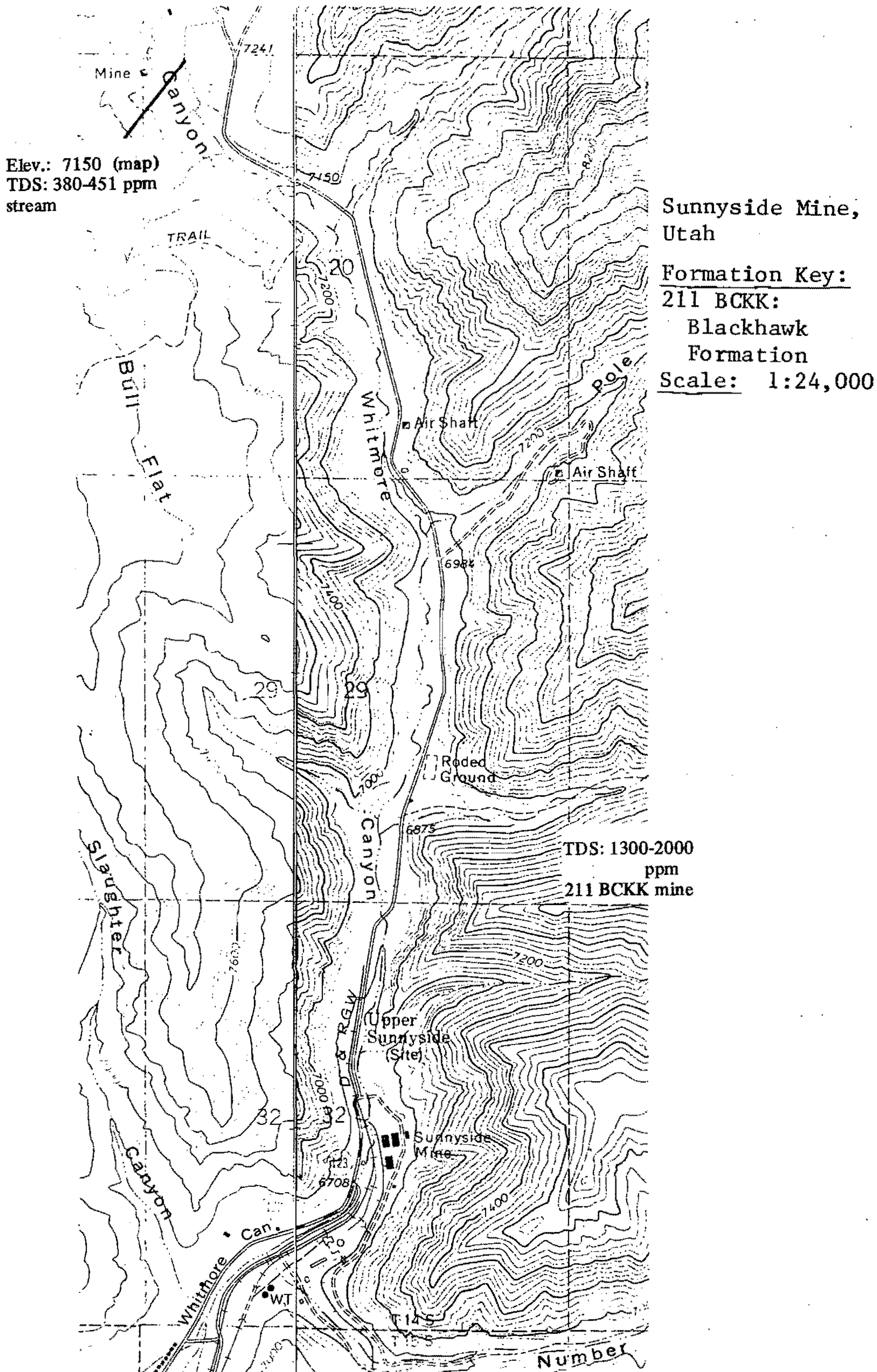


Figure 3.5. TDS concentrations of water in and around Sunnyside mine, Utah (Patmos Head and Sunnyside quadrangle from U.S. Geological Survey).

levels in discharged minewater averaged 1,760 ppm during 1977. A shallow well near the mine but not over the mine workings displayed a TDS concentration of 1,760 ppm in 1978, and concentrations in the surface stream above the mine averaged 1,320 ppm from 1974-1976. Springs emanating from both canyon walls above the mine discharge water with lower TDS levels, indicating the concentration of salts increases with the distance traveled through the ground. Discharged minewater quality, therefore, reflects the local groundwater and surface water conditions. If water were not intercepted by the mine, it would probably travel downdip to the Uintah Basin. Its final disposition and quality would be similar to that discussed in the "Sunnyside mine" section. Consequently, it is probable that discharging intercepted groundwater from the Geneva mine to surface streams also represents a net decrease in the salt load to the Colorado River.

Hiawatha mine. The Hiawatha mine is located in Townships 15 and 16 South and Ranges 7 and 8 East and covers more than 17 square miles. TDS levels of water in and around the mine are shown in Figure 3.7. Groundwater intercepted in the mine comes primarily from the Bear Canyon fault (personal correspondence, confidential source), and travels as much as 5 miles underground before it leaves the mine through the abandoned Mohrland portal. The average TDS concentration of minewater discharge (700 ppm) is higher than the concentrations found in the surrounding springs. The increase is probably due to the long travel distance over mined out areas and the natural salt pick up in the strata immediately above the mine.

While the minewater discharge has a higher TDS concentration than local springs, it is still used beneficially by both agriculture and a municipality and dilutes the salinity of the Colorado River. If not intercepted by the mine the groundwater would probably continue to travel along the Bear Canyon fault. Its final disposition is unknown.

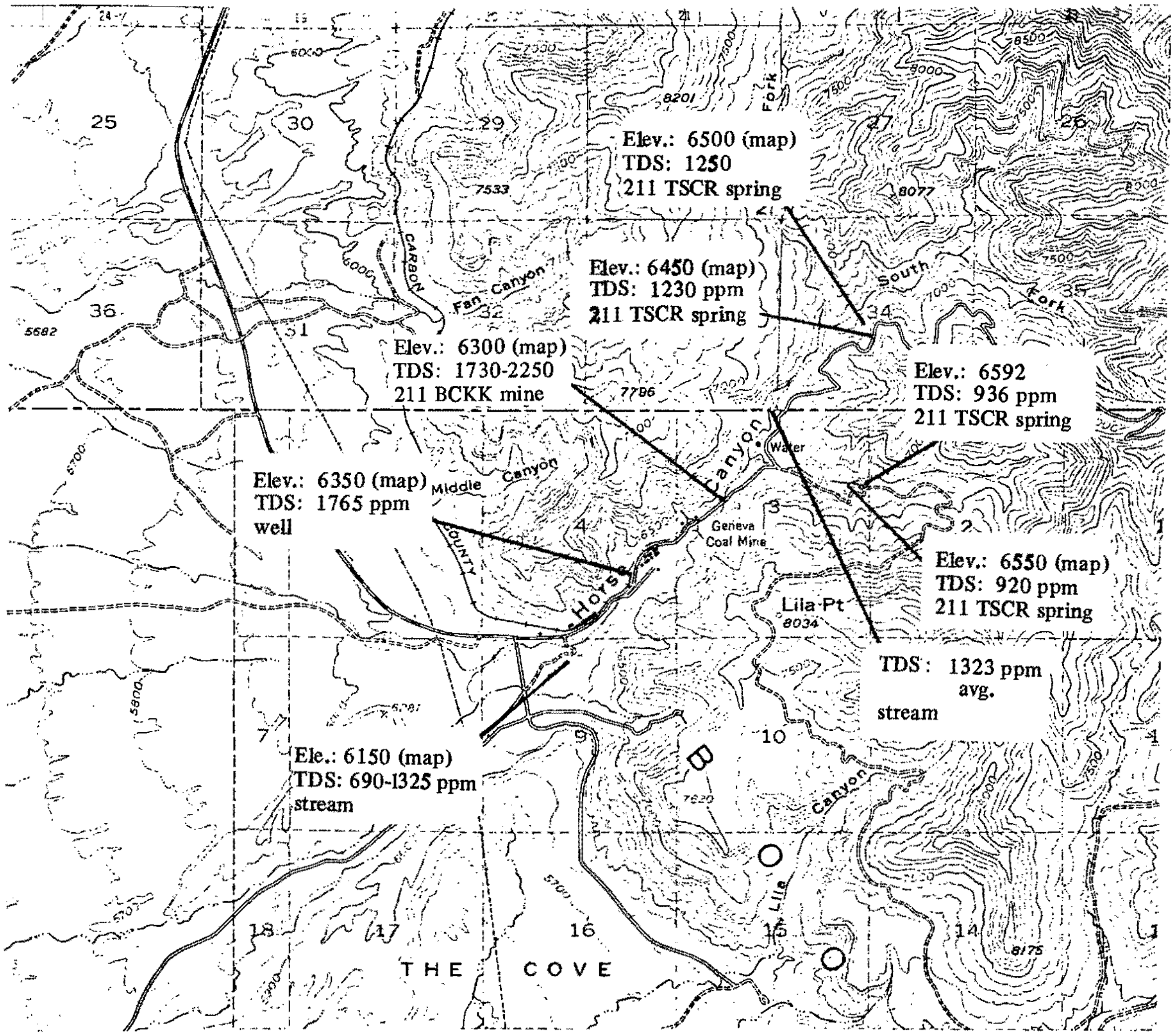
Wilberg mine. The Wilberg mine is located in section 27 of Township 17 South and Range 7 East. TDS concentrations for the mine and area are shown in Figure 3.8. An increase in TDS concentration as elevation decreases is apparent throughout the area. The water intercepted at the mine has an average TDS concentration of 540 ppm as compared to approximately 760 ppm in Grimes Wash, 2 1/2 miles to the south. Data from Intermountain Consultants and Planners (1977a) reveal only a 6 percent increase (470 to 490 ppm) in TDS levels as water proceeds through the mine and is discharged at the portal. Based on available data, therefore, intercepting groundwater in the Wilberg mine preserves water quality and removes it for beneficial use in the area and represents a decrease in the salt load of the Colorado River.

Convulsion Canyon mine. The Convulsion Canyon underground coal mine is located in section 12 of Township 22 South and Range 4 East. TDS concentrations in local water are presented in Figure 3.9. The TDS concentration of the intercepted groundwater in the mine is comparable to that of local springs and surface waters, and its average concentration of 325 ppm is well below the TDS concentration of the Colorado River. If not intercepted by the mine, the groundwater Convulsion Canyon through a surface spring. If, however, the groundwater continued downward and entered deeper aquifers, its salt load might increase to as much as the 2,400 ppm found in a well 4 miles to the west, which removes water from the same geologic formation (see Table 3.3). Removing the groundwater at the mine level, therefore, preserves water quality and makes available good quality water for beneficial use.

Emery deep mine. The Emery deep mine is located in the Ferron sandstone member of the Mancos shale group in sections 28, 29, 32, and 33 of Township 22 South and Range 6 East. TDS concentrations of intercepted groundwater and of local springs and streams are shown in Figure 3.10. Mine depth varies from zero to approximately 500 feet. The average TDS concentration of discharged groundwater is 4,625 ppm. Approximately two-thirds of the minewater, seeping from a sealed off area 125 to 200 feet below surface streams, has a TDS level of 6,500 ppm (see results section of Chapter II under Emery mine). As was stated in Chapter II, Quitchupah Creek and Christiansen Wash, two streams in the immediate vicinity of the mine which contain significant volumes of agricultural return flow, average a TDS of 5,000 ppm.

The minewater discharge TDS concentration of 4,625 ppm far exceeds the Colorado River base figure of 839 ppm. The high TDS levels of minewater discharge probably result from the mixing of relatively fresh Ferron sandstone groundwater (1,000 ppm) with the saline water flowing from the sealed portions of the mine (6,500 ppm). This saline water probably comes from deep percolation from the overlying saline surface streams. Deep percolation is possible at this location because the mine creates a "hole" in the hydrostatic pressure within the Ferron formation.

If the mine were non-existent, the groundwater from the Ferron sandstone would discharge into Quitchupah Creek and Christiansen Wash (see Figure 2.3). The 1978 Mining and Reclamation Plan for the Emery mine states: "the results of chemical analyses of water samples collected from Quitchupah Creek and Christiansen Wash show a



Geneva Mine T. 16S., R. 14E.

Formation Key: 211 BCKK: Blackhawk Formation
211 TSCR: Tuscher Formation

Scale: 1:62,500

Figure 3.6. TDS concentrations of water in and around the Geneva mine, Utah (Woodside quadrangle from U.S. Geological Survey).

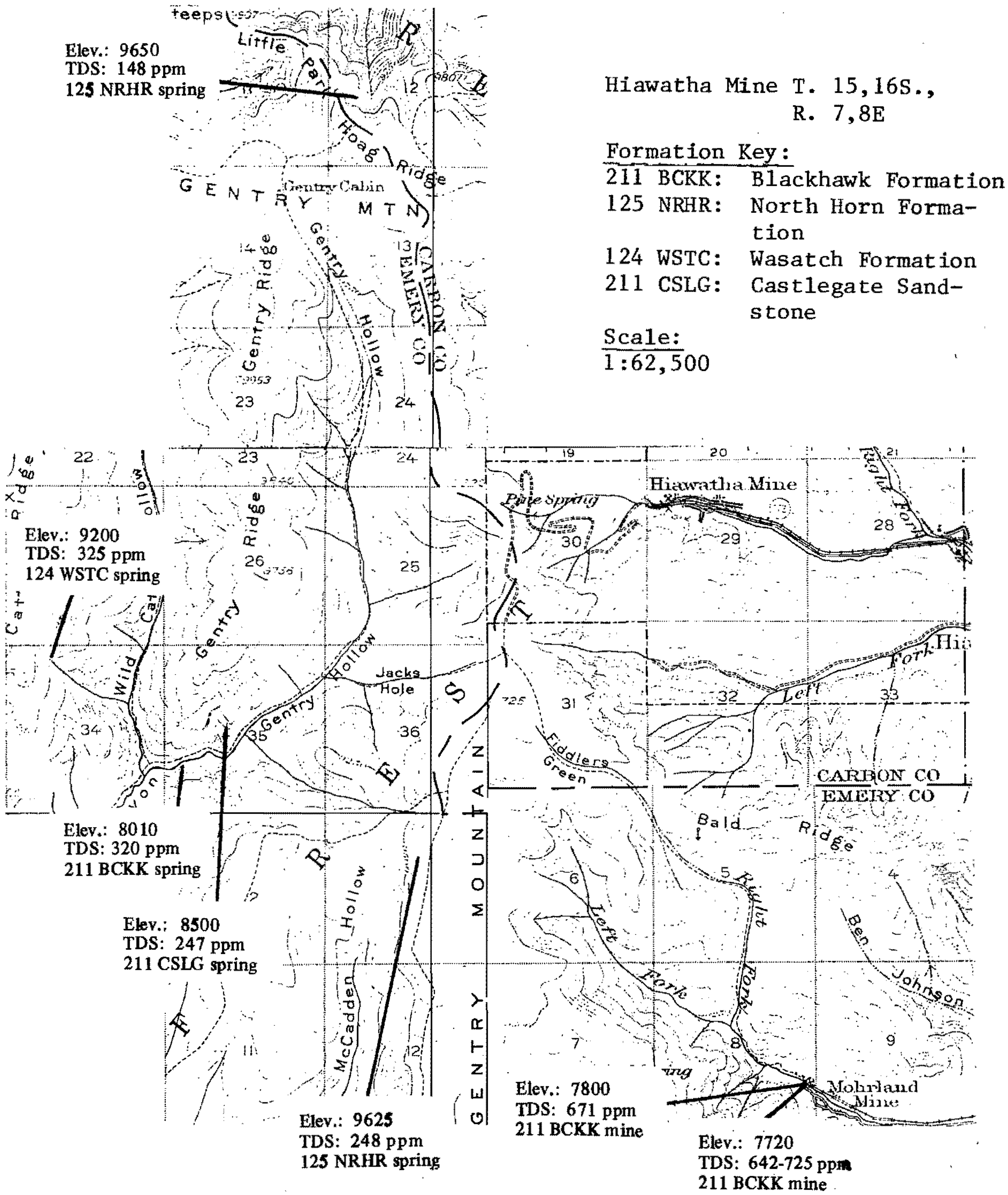
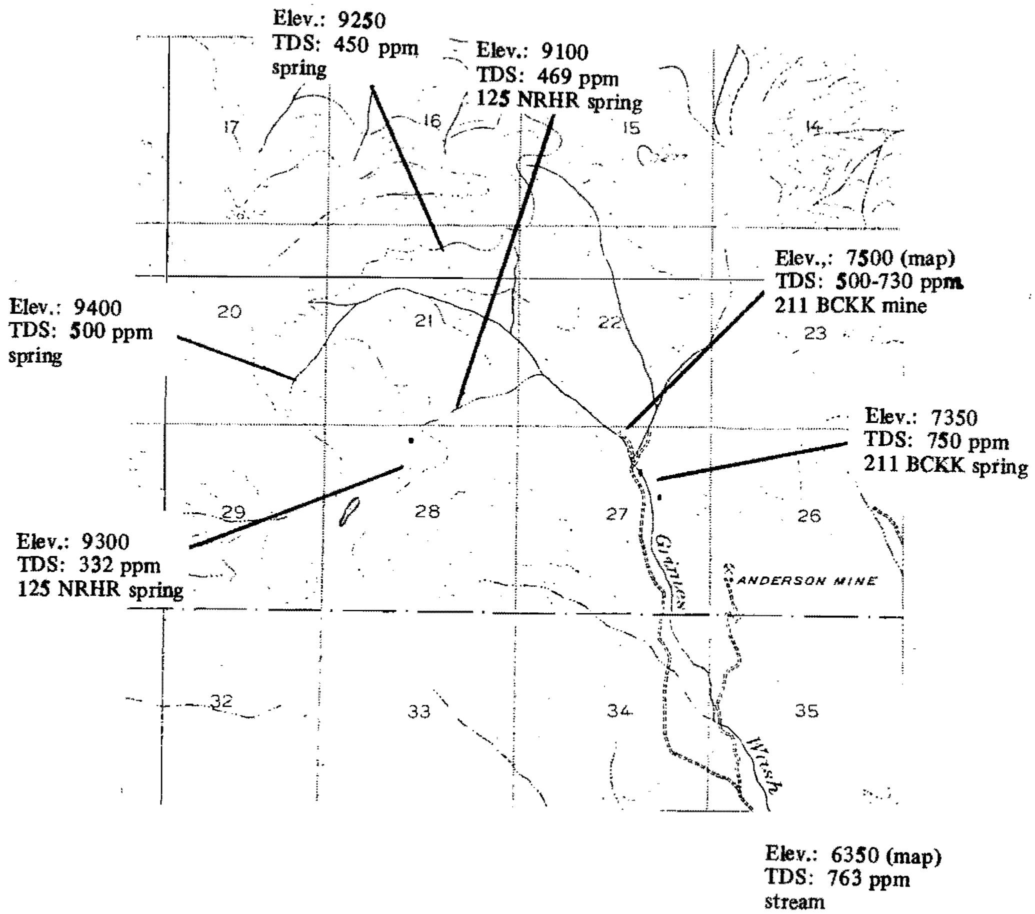


Figure 3.7. TDS concentrations of water in and around Hiawatha mine, Utah (Hiawatha and Scofield quadrangles from U.S. Geological Survey).



Wilberg Mine T. 17S., R. 7E., Sec. 27

Formation Key: 211 BCKK: Blackhawk Formation
125 NRHR: North Horn Formation

Scale: 1:62,500

Figure 3.8. TDS concentrations of water in and around Wilberg mine, Utah (Scofield quadrangle map from U.S. Geological Survey).

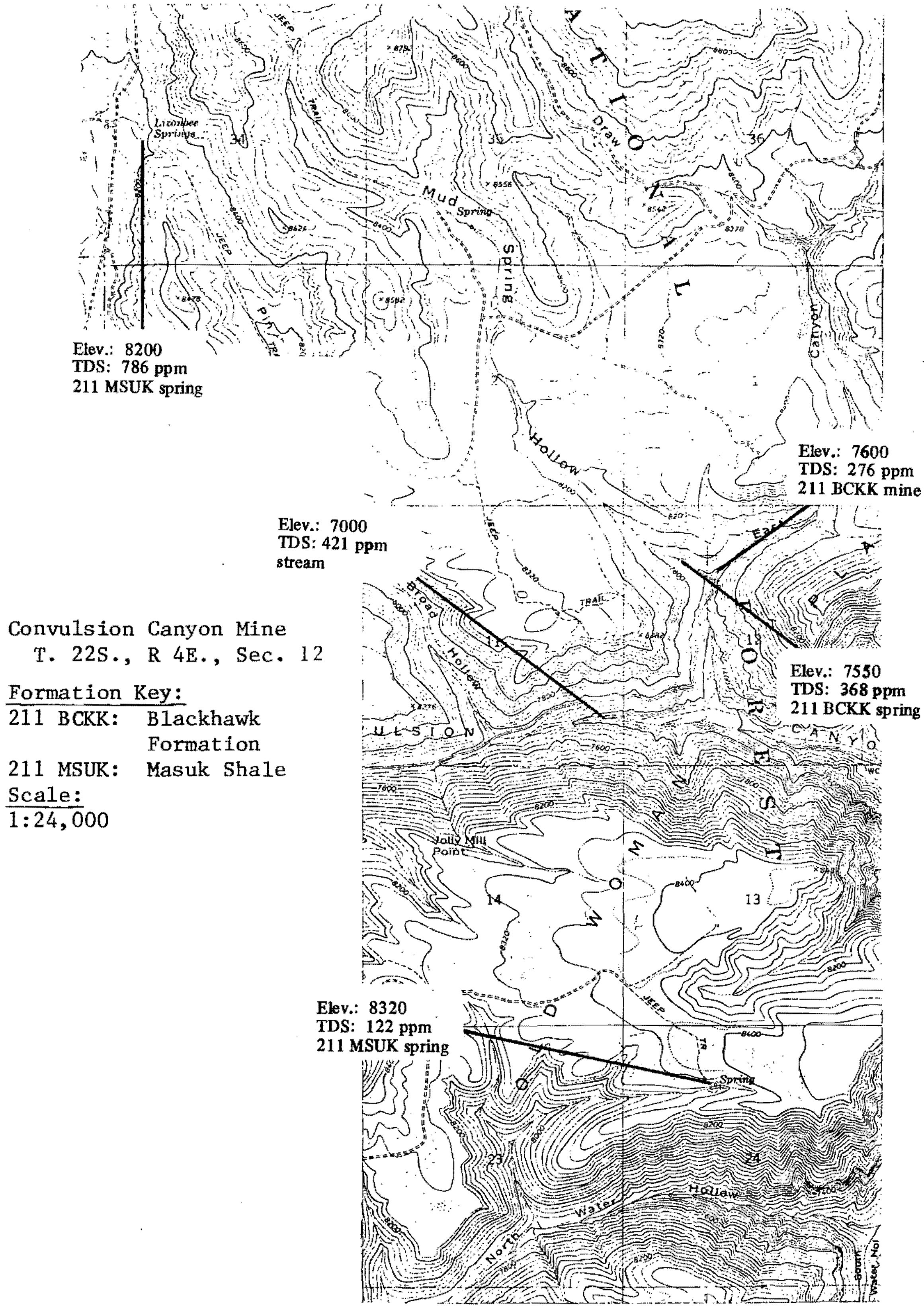


Figure 3.9. TDS concentrations of water in and around Convulsion Canyon mine, Utah (map from U.S. Geological Survey).

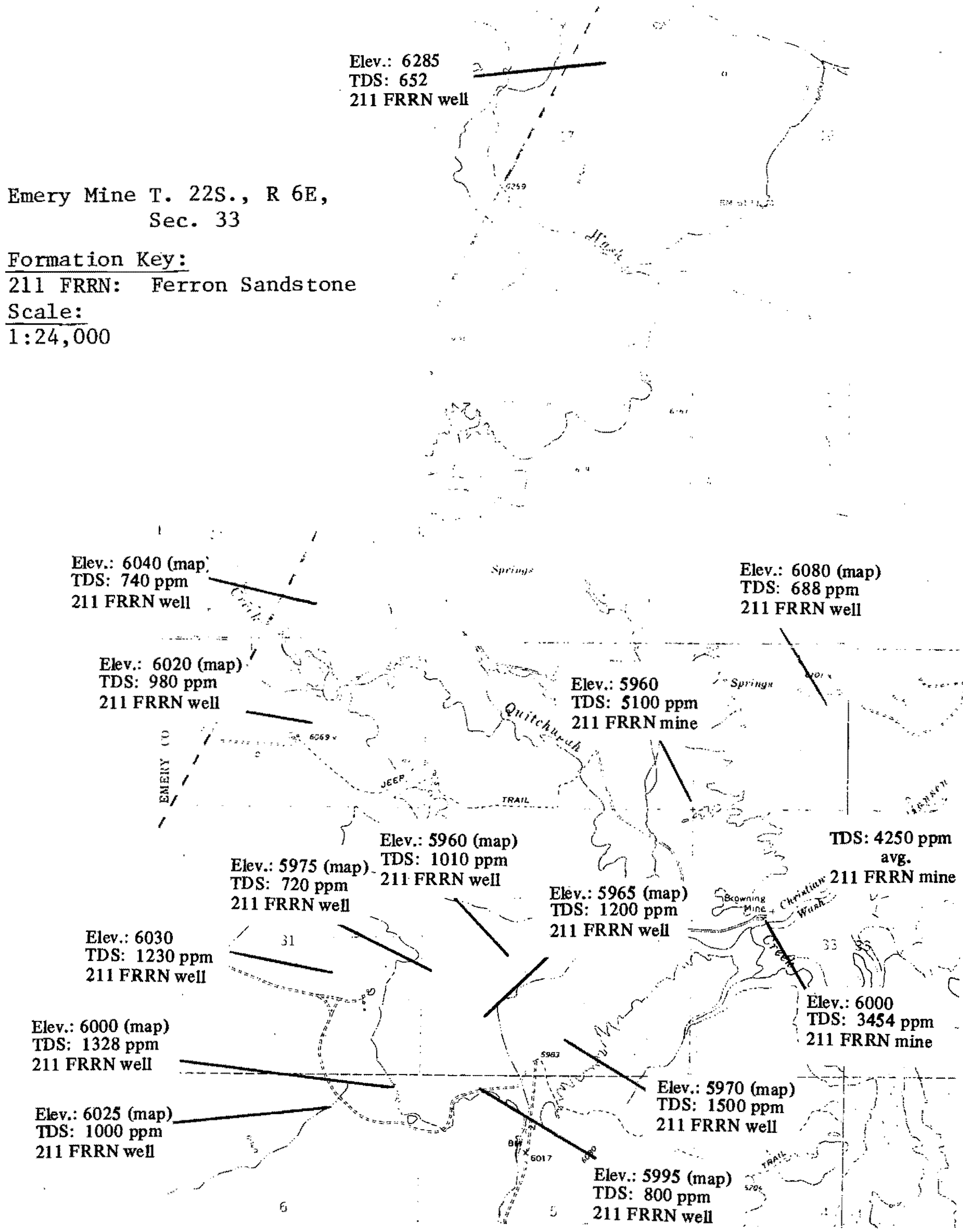


Figure 3.10. TDS concentrations of water in and around Emery mine, Utah (Emery West, Mesa Butte, and Walker Flat quadrangles from U.S. Geological Survey).

measurable decrease in total dissolved solids concentration where the streams flow through the Ferron sandstone outcrop." The resultant TDS level would probably be higher than the TDS level of the Ferron sandstone groundwater and lower than the TDS level of the surface streams, and similar to the average of 4,625 ppm in discharged minewater. The mine, then, instead of the surface streams, is the mixing location for the two different groundwater resources in the area--the Ferron sandstone groundwater and local agricultural return flow. Mining operations, therefore, seem to have a negligible impact on groundwater quality and do not represent a source for increasing the salt load to the Colorado River.

Other mines. Data for the seven remaining mines shown in Table 3.4 were not sufficient for site-specific analyses. However, TDS levels in five of the six mines where water quality samples were available are under 839 ppm. The single sample taken from the Knight mine has a much higher level of TDS.

CHAPTER IV

OPPORTUNITIES FOR USING ABANDONED COAL MINES TO STORE WATER

The purpose of this chapter is to discuss opportunities for using abandoned underground coal mines to store water. An underground coal mine is abandoned when extraction operations have ceased, extraction equipment is removed, and operations are not anticipated to resume. First, the advantages of underground water storage will be presented. One of the greatest is the potential reduction of evapotranspiration losses. Next, the current practice and purpose of water storage in active coal mines will be documented. Finally, considerations in underground storage site selection will be discussed along with the steps in the development of underground reservoirs and potential problems.

Advantages of Underground Reservoirs

Underground reservoirs, whether the result of man's activities or occurring naturally in permeable geologic strata, have several advantages over storage in surface reservoirs. Among these are:

1. Once storage space is excavated, the reservoir costs very little to develop provided water can drain out of the mine by gravity.

2. There are relatively small storage losses due to sedimentation.

3. There are no losses of water to evaporation.

4. The water is stored at a relatively constant temperature and mineral content.

5. The water is not turbid except in some limestone or volcanic areas with high secondary porosity.

6. The reservoir does not pre-empt surface water use.

7. The water is not subject to eutrophication.

8. The supply is relatively immune to radiological contamination from nuclear warfare.

While all of these advantages are important, the reduced evaporative losses are of particular significance in the arid climate of Utah.

Evaporation Losses

Utah's coal mines are located in an arid environment. Cities and towns serving the mining industry commonly are in areas where annual potential evapotranspiration is from 24 to 30 inches (Jeppson et al. 1968). Evaporation losses from surface reservoirs are approximately equal to potential evapotranspiration (Linsley and Franzini 1972). Thus, for example, if a surface reservoir covering 1,000 acres were constructed near Wellington, Utah, where annual potential evapotranspiration is 30 inches, water loss from evaporation would be 30 inches a year, which, when distributed over the reservoir, would be equivalent to 2,500 acre-feet per year. Assuming an average per capita water demand of 250 gallons per day (Hansen et al. 1979), evaporation from the surface reservoir would equal the water used by a community of 8,000 people in one year, a population about as large as that of any town in the area. Thus, surface storage sacrifices large volumes of already scarce water, and the use of abandoned mines to store water underground could be a significant hydrologic benefit.

Current Use of Stored Water

Groundwater inflow may be of such magnitude that if it were not removed, the mine would eventually fill with water, as has occurred at the Braztah Peerless mine in Hardscrabble Canyon. The mine, abandoned almost 50 years ago, has filled with an estimated 900 acre-feet of water (Israelsen, personal communication, 1979). The water must be pumped out before mining can recommence.

Currently several active coal mines in central Utah are used to intercept and temporarily store groundwater in abandoned areas of the mine (Table 2.1). The intercepted groundwater usually flows downdip along the mine floor to the lowest part of the mine where it is pumped to the surface and beneficially used. Uses being made of the intercepted and stored groundwater include:

1. Bathing water
2. Drinking water
3. Irrigation of public parks and lands
4. Dust suppression within the mine
5. Cooling water for a coal-fired electric generating plant

This experience suggests a potential for storing intercepted groundwater in abandoned coal mines.

Factors Conducive to Underground Storage of Water

Developing an underground reservoir in an abandoned coal mine, like siting a surface reservoir, requires consideration of many factors, including:

1. The method of coal extraction. The room and pillar method of mining is the most advantageous for post-mining storage of water. The rooms from which the coal has been removed leave large volumes available for water storage after the mine is abandoned. The longwall method of mining, while not leaving large open rooms for water storage, may still provide sufficient void space to make post-mining water storage feasible. The voids left in the collapsed roof material would have a large void volume and provide considerable potential for storing water in the artificially created permeable aquifer.

2. The presence of a confining layer beneath the coal. An impermeable layer beneath the coal would act as a bottom seal for the underground reservoir, reducing losses of water from the mine through vertical percolation. Such a condition exists at the Emery deep mine:

> A four to five foot layer of relatively impermeable clay and shale located immediately below the coal floor apparently retards any vertical flow of groundwater into the mine (Consolidation Coal Company 1978, p. 28).

The same clay layer would also prevent vertical flow out of the mine. The mine currently uses abandoned mined out areas to temporarily store water.

3. Absence of faulting which conducts water away from the mine. Faults may conduct water into or out of a coal mine. For example, the Hiawatha mine receives a significant portion of its minewater inflow from the Bear Canyon fault (Chapter II), but the Belina No. 1 mine, 10 miles to the north, is intersected by a fault which conducts intercepted water through the coal floor. Thus, the absence of faulting which may conduct groundwater away from the mine is an important factor in successfully developing an underground reservoir.

4. Source of water. Water for underground storage may naturally flow into the mine or be conveyed to the mine through a pipe or canal. If the source is within the mine, it is important that it is identified and protected after abandonment. Otherwise, inflow may be reduced or even eliminated by roof caving.

5. Uncontaminated contact surface. It is important that the mine be free of contamination sources. Trace elements can be particularly troublesome.

6. Economically close to need. An abandoned underground coal mine may be so far from where storage is needed that construction of conveyance systems for water transport to the area would prove economically infeasible. The final destination of water in the underground reservoir should be considered.

7. Aspect of coal seam. Obviously, a coal seam must be oriented downdip to the mountain mass in order to store water in abandoned workings.

General Procedure for Developing an Underground Reservoir in an Abandoned Coal Mine

Once the above criteria have been used to select a suitable site, its development for water storage requires the following steps:

1. Grout or seal all faults and cracks which do not contribute groundwater to the mine.

2. Remove point sources of pollution from the mine such as sacks of rock dust, hydraulic fluid containers and corrosive metals.

3. Apply a substance to absorb the oil and grease generated in the mine from daily operation.

4. Spray wash the rock dust from the walls and ceiling.

5. Install the necessary pumps and pipelines. If the room and pillar method of mining was used, pumps and lines may be located inside the mine. If, however, longwall methods were used to extract coal, a "well" will need to be developed from the ground surface above the mine to tap the confined aquifer created by roof falls.

6. Pump out any initially polluted groundwater until pollution levels reach equilibrium values.

7. Install appropriate water treatment facilities commensurate with the intended use of the water.

8. Locate test holes from the ground surface to the reservoir to allow periodic water quality tests to be made.

Special Problems

In addition, each site presents special engineering problems that must be solved in order to use the abandoned workings to store water.

Location of inflow source

In many cases water flows freely into mines from the surface or from overhead perched aquifers. Subsurface inflow will stop when the water level in the filling reservoir reaches the level of groundwater inflow. Whether the resulting equilibrium volume would be small or large would depend on the location of groundwater inflow sources. If inflow sources are deep within the mine, and a small equilibrium storage volume results, supplemental water may be needed to increase storage to meet design demands.

Equipment maintenance

Underground submerged pumps and pipes would be nearly inaccessible in deep regions of the mine. Appropriate operation and maintenance procedures should be an integral part of the design process.

Underground leaks

Underground leaks caused by residual cracks and high water pressure in the reservoir would be difficult to locate and seal. Major leaks would require the reservoir to be drawn down and repaired.

Development of a reservoir from a longwall operation

Caving immediately follows the mining face in longwall mining operations, making impossible the sealing of floor cracks and the removal of oil and grease from the caved-in material. The inability to inspect or repair the created reservoir might further limit the potential for using abandoned longwall mines as underground reservoirs.

Groundwater contamination

Contaminants in the stored groundwater may include sulfur compounds and heavy metals leached from the coal, dissolved solids from overlying strata, and man-made pollutants left by the mining operation. The cost of removing these contaminants can be considerable.

Potential Storage Capacity of Historic Geneva Mine

The Geneva mine, located in Township 15 South and Range 14 East, has been operated since 1941 (Doelling 1972) to remove an estimated 30 million tons of coal by the room and pillar method. Assuming the unit weight of coal is 85 pounds per cubic foot, the rooms represent a possible storage capacity of 16,200 acre-feet. The actual capacity is somewhat less because some caving has followed the removal of pillars on retreats from mine limits.

CHAPTER V

A SUMMARY OF THE POTENTIAL EFFECTS OF SUBSURFACE MINING ON WATER RESOURCES

Underground coal mines in Utah discharge approximately 5,900 acre-feet of intercepted groundwater annually. It is important to identify the sources of these groundwater inflows in order to determine what effect the mine has had on local water quality and quantity. The effects depend on the location of the mine with respect to local groundwater, the extent of subsurface cracking and surface subsidence produced by the mine, and the mining operation management policies.

The purpose of this chapter is to discuss the potential effects of underground coal mining in Utah on the quality and quantity of local water resources. The emphasis is on effects related to:

1. The location of the mine with respect to local groundwater.

2. Subsurface cracking and surface subsidence induced by the mine.

3. Mining operation management policy.

Following this discussion, the importance of determining the effects of mining on local water resources will be assessed.

Effects on Water Resources as Influenced by the Location of the Mine

Whether an underground coal mine is located above or below the local groundwater table may be a major factor in determining the potential effects on local water resources. Mines above groundwater tables may intercept percolating waters that would eventually reach surface springs. Mines intercepting saturated groundwater aquifers, in addition to potential impacts on surface springs, may change the groundwater hydrologic divide.

Mining above a regional groundwater table

Underground coal mining in Utah is usually done above regional groundwater tables (Chapter II). Such mines may potentially influence surface springs and alter the hydrologic balance of the area.

Influence on surface springs. Underground coal mines commonly intercept perched aquifers and deep percolation from the ground surface. Perched aquifers may consist either of water that is trapped underground, having neither inflow nor outflow, or may discharge to local springs. Springflow originating in perched aquifers intercepted by underground mines may decrease or even cease.

Intercepting deep percolation may also affect surface springs. Perched aquifers below the coal seam may be fed by deep percolation from the ground surface. As they fill, they may discharge intermittently or continuously to surface springs. If underground coal mines intercept this source of water, springflow may decrease or even stop.

Influence on local hydrologic balance. Intercepted groundwater is either pumped out of the mine or flows out by gravity. In either case, the effluent represents a point discharge of groundwater collected throughout the mine. The mine discharge may consist of water that was previously discharged from surface springs or water that contributed to stream baseflow. Water that previously discharged into one watershed may be rerouted by the mine to the watershed in which the pump or portal is located, thus decreasing streamflow in one or more watersheds while increasing it in another. The change in discharge point may seriously affect downstream water rights.

Mining in a regional groundwater table

Some underground coal mines in Utah (the Emery deep mine and the Utah No. 2 mine, for example) apparently intercept or are located in regional aquifers. Such mining operations may affect local springs, streams and wells and change the hydrologic divide.

Influence on local springs, wells, and streams. Groundwater aquifers may discharge into springs, wells, or streams. An underground mine may intercept groundwater flow in the aquifer and change its discharge point. Downstream discharges from springs, wells, and streams may decrease or even cease.

Influence on groundwater divide. An underground coal mine that intercepts a groundwater aquifer may change the location of the groundwater divide. In such a case, as mining proceeds into the coal seam, the groundwater aquifer would drain, lowering the groundwater table. The groundwater divide would then change to coincide with the working face of the mine (where coal is being removed) until the water table drops below the coal seam. The location of the hydrologic divide will have been changed from its natural location. If the mine were to progress to elevations less than those of the local surface streams, what once were effluent streams may become influent streams, contributing to groundwater flow and decreasing flow in the stream channel.

Effects on Water Resources Due to Subsurface Cracking and Surface Subsidence

The location of underground coal mines with respect to the local groundwater table is not the only factor that may affect local water resources. Underground coal extraction causes subsurface cracking and may cause some surface subsidence. This subsurface and surface ground displacement may also affect water resources.

Subsurface cracking

Subsurface cracks emanate from underground coal mines as the overlying strata flexes in response to compressive or tensile stresses created by the extraction of coal and by roof falls over mined out areas (Dunrud 1976). While cracks created by roof falls usually terminate within 100 feet above the mined out area, the more serious tension and compression cracks created by the flexure of strata sometimes reach the ground surface.

Cracks terminating before they reach the ground surface may affect local water resources in three ways. First, they may tap perched aquifers above the coal seam and decrease the discharge of such aquifers to surface springs. Secondly, they may intercept a groundwater flow path crossing above the mine and channel the flow vertically downward into the mine. Thirdly, the crack may intersect overlying confined or unconfined aquifers, lowering the piezometric head and creating a groundwater flow path to the mine.

The cracks that reach the ground surface are usually caused by the flexure of overlying strata as they respond to the extraction of large expanses of coal. Figure 5.1 shows a cross section through the southern sections of the Book Cliffs and Geneva mines where the compression cracks surfacing at point 2 are the result of the downward bending of strata between two coal pillars. The tension cracks at points 1 and 3 resulted from the downward bending of the strata on both sides of coal pillar number 1.

Such surface cracks may divert surface flow into the ground, where it may percolate into the mine and later appear as a surface spring. Stockwatering ponds, or any other body of water intersected by a surface crack, may also drain into the ground. Finally, surface cracks would increase the volume of deep percolation from surface precipitation. These effects, however, decrease with time as the cracks fill with sediment from surface water inflow.

Surface subsidence

Surface subsidence is the lowering of the ground surface as a result of underground coal mining. The magnitude of surface subsidence depends on the overburden depth

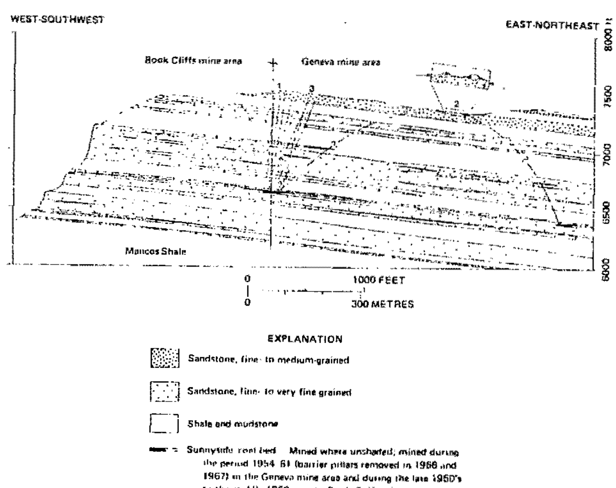


Figure 5.1. Cross section of the rocks of the Upper Cretaceous Mesaverde Group in the southern parts of the Book Cliffs and Geneva mines, Utah. Major deformational features in rocks above the mined-out areas and adjacent barrier pillars are based on a map by Dunrud and Barnes (1972). (1) First set of tension cracks, (2) compression features probably caused by a compression arch, and (3) a second set of tension cracks (taken from Dunrud 1976, p. 11).

and the type of strata overlying the mine. Unless underground cavities exist above the mine, surface subsidence could not exceed maximum mining height, which is usually about 14 feet. Dunrud (1976), for example, found that surface subsidence over a Colorado coal mine equaled 0.6 times the mining height.

Surface subsidence may disrupt shallow groundwater aquifers and change the direction of surface flow to create small surface lakes. If vertical cracking accompanies the subsidence, water may be diverted from the surface into the ground and reappear elsewhere.

Effects on Water Resources as Influenced by Mining Operation Management

Certain effects on water resources depend on such mine operation or management decisions as those on the progression of coal extraction and mine maintenance.

Progression of coal extraction

The extraction scheme in the room and pillar coal mining method controls the extent of surface subsidence and subsequent changes in local water disposition. Schemes can be designed to minimize surface subsidence. At the opposite extreme, Bauner (1973) shows extraction schemes that produce maximum surface subsidence and differential displacement (see Figure 5.2). These extraction schemes, with their attendant surface subsidence, would most seriously affect local water resources.

Mine maintenance

Results in Chapter III showed that underground coal mines in central Utah do not significantly increase the total dissolved solids concentrations of intercepted groundwater. Mines do, however, add oil and grease and other contaminants used during the mining process to intercepted groundwater. Mine maintenance can minimize any detrimental effect by minimizing contact with contaminants or treating discharged minewater appropriately.

Importance of Determining the Impacts of Underground Mines on Water Resources

Since underground mines can redistribute water in time or space and change its quality, it is important to determine what effects each coal mine has on local water resources. The need is reflected in a statement by the Office of Surface Mining Reclamation and Enforcement in its permanent regulatory program:

> Any person who conducts underground mining activities shall replace the water supply of an owner of interest in real property who obtains all or part of his or her supply of water for domestic, agricultural, industrial, or other legitimate use from an underground or surface source, where the water supply has been affected by contamination, diminution, or interruption proximately resulting from the underground mining activities (Section 817.54, p. 15430, Federal Register 1979).

Thus, federal law requires operators of underground mines to replace any water loss in quantity or quality to prior users as a result of the mining operation. Whether or not a coal operator is held responsible for changes in local water resources depends on the successful determination of the origin of groundwater entering the mine.

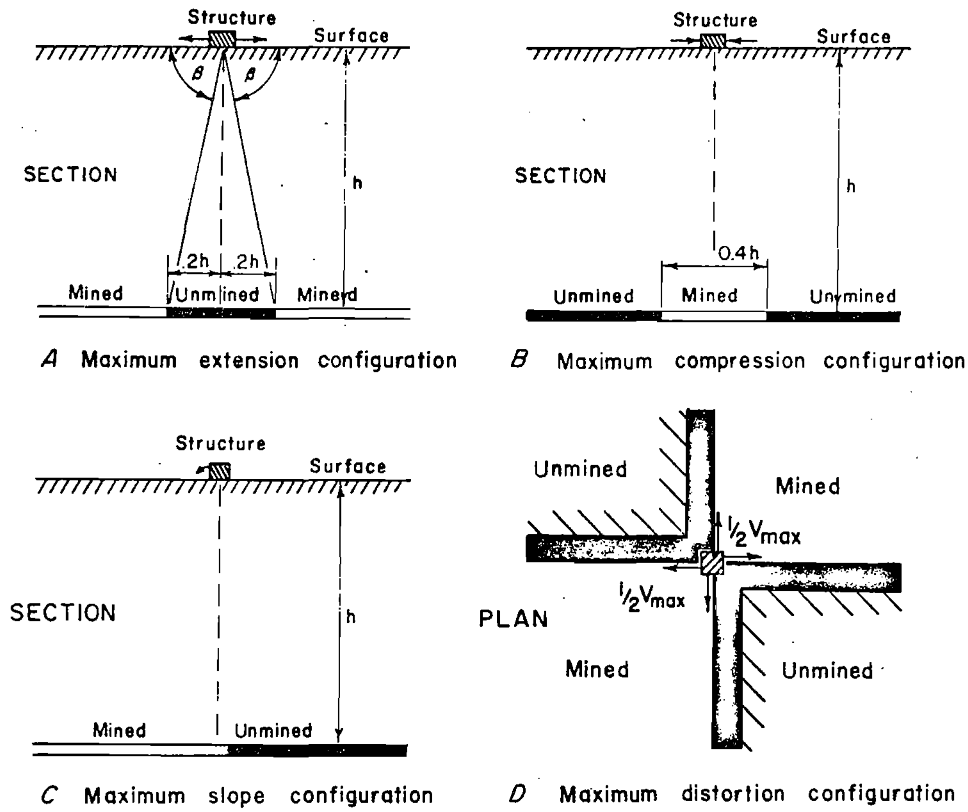


Figure 5.2. Unfavorable extraction schemes (adapted from Brauner 1973, p. 25).

CHAPTER VI

SEDIMENTATION--ITS OCCURRENCE AND TREATMENT POTENTIAL IN THE UPPER COLORADO RIVER BASIN

The objective of this chapter is to assess the potential for using surface coal mines in Utah to 1) control the sediment load to the Colorado River and 2) enhance water storage in the basin (Figure 1.3). The introductory discussion of projected surface coal production in Utah is followed by a review of the positive and negative hydrologic impacts that might accompany surface mining operations, and a review of methods for controlling erosion from surface mined lands. A section on methodology summarizes the steps taken to complete the objective, and the remainder of the chapter discusses results of the investigation.

Introduction

Through 1972, Utah produced only 6,000 tons of coal by surface mining methods, leaving 150 million tons of coal as strippable reserves (National Academy of Sciences 1974). However, with the expected increase in demand for coal in the next decade, Utah surface mine production is projected to increase to 13 million tons per year by 1990 (Nielson 1979 and U. S. Geological Survey 1978f).

Surface mining in the past has been accused of seriously disrupting stream and river channels and increasing sedimentation as much as 1,000 times (Udall 1967 and Collier et al. 1964). These adverse environmental impacts are of particular concern in the Colorado River Basin of Utah where water is scarce and sedimentation already is a problem. But proper mining techniques may minimize such hazards and in some cases even create hydrologic benefits--that is, enhance water storage in the basin and reduce sedimentation to the Colorado River.

Hydrologic benefits of coal mining

A typical surface mining operation is shown in Figure 6.1. Earth and rock (overburden) above the coal seam are removed and cast to one side and the exposed coal is broken up and loaded into trucks. Overburden from the next cut is placed where the coal has just been removed.

The volume of the disturbed overburden is approximately 30 percent greater than in its natural state (Herring 1978). Post mining infiltration rates in the cast overburden are often higher than in the surrounding natural soil (Corbett 1978), allowing greater recharge of precipitation and subsequent base flow during dry months (Agnew 1971). These overburden characteristics constitute important hydrologic benefits to the system.

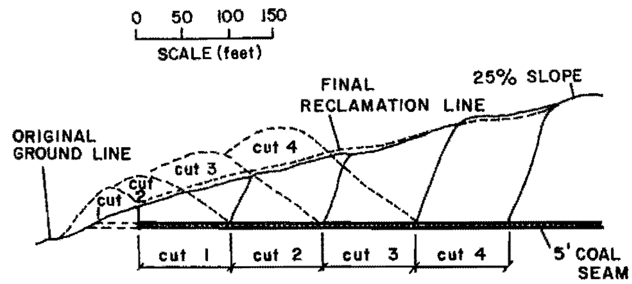


Figure 6.1. Typical surface mining operation (after Civil Engineering 1977a).

Corbett (1978) discusses another possible hydrologic benefit of surface coal mining resulting from proper management of the final cut made in the operation:

> Based on current surface mining operations in the recovery of coal, it is not uncommon for the final cut pit to exceed a mile in length and 100 feet in depth. The highwall side of the pit is almost vertical, usually comprised of rock, shale and some till near the top. The bottom of the pit, which will average about 100 feet in width, is usually comprised of a tight underclay impermeable to water penetration; the overburden side is usually comprised of loose upturned material with side slopes ranging from 1 foot vertical to 1-1/4-1-1/2 feet horizontal. This final cut pit and adjacent cast overburden (spoilbank) can be converted into a water storage reservoir combine at relatively low cost to the developer.

There are at least three ways (which may work independently or in conjunction with one another) that this pit-cast overburden combine can receive water:

1. From precipitation falling directly upon its surface--This is perhaps the most common source of supply, especially in humid areas where the average annual precipitation exceeds 40 inches. When the upturned material (cast overburden) is left unmolested and naked, water salvage from the disturbed area will then be at its maximum. The loose top material will readily absorb the precipitation and carry it well below the influence of evaporation, and being relatively free from vegetation, there will be very little loss of water through vegetal transpiration. Under such conditions, as much as 80 percent of the total precipitation falling on the cast overburden will be temporarily stored in the combine for later release when supplies are less plentiful. This applies whether the average precipitation is 10 or 60 inches over the disturbed area.

2. Diversion of surface runoff from adjacent areas--Diversion can occur either directly into the pit from adjacent tributary watersheds, or into the cast overburden from unmined upstream headwaters in the same watershed containing the mining operation. A combination of both procedures may also be practical and will hasten filling of the combine with water.

Diversion procedures will be found to be most productive in arid and semi-arid regions where the average annual precipitation is 20 inches or less. When grading and reseeding is required, as part of the land restoration plan, a large portion of the precipitation will be used up in sustaining plant growth. When the annual precipitation is less than 10 inches, salvage from rain water will be nil unless the upturned material is left untouched.

3. From ground water supplies that had not been tapped but that had been intercepted during the mining process--This water is usually good quality and can make a sizable contribution toward maintaining a final cut lake. There have been occasions where mining operations had to be abandoned because of excessive inflow into the operating pit from highly permeable sands, gravel, and slides caused by natural water pressure within (p. 84).

Conceptual drawings of the creation of a "last cut lake" are shown in Figure 6.2.

Thus, Corbett identifies a procedure to enhance water storage in a surface mined area by leaving the last cut pit open to collect precipitation, runoff and groundwater flow. Such surface lakes may provide recreation (Udall 1967) and sometimes municipal water supply (Herring 1978).

Corbett (1976) also explains that last cut pits may serve as natural sedimentation reservoirs, trapping sediment from surface runoff and preventing its transport to downstream channels. This is of particular importance in the Colorado River Basin. Any sediment entrapped in last cut pits would not reach the Colorado River. The overall effect, however, depends on the sediment regime in the river between the mined area and the river.

Whether surface mining becomes a hydrologic disaster or benefits natural watersheds depends on the management techniques used during mine operation. The remainder of the chapter assesses the potential for using surface coal mines in Utah to reduce the sediment load to the Colorado River and enhance water storage in the basin.

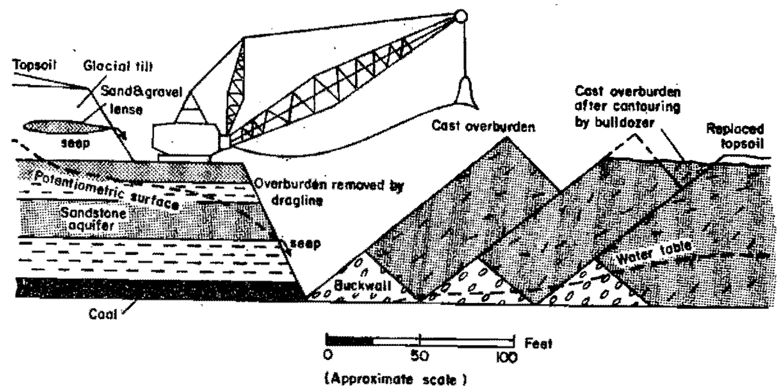
<u>Controlling erosion from surface mined lands</u>

Current federal law requires that cast overburden from surface mining operations be regraded to its approximate original contour (Federal Register 1979). Such regrading, however, with resultant long, unbroken slopes and slightly compacted soil often increases erosion (Herring 1978 and Corbett 1978).

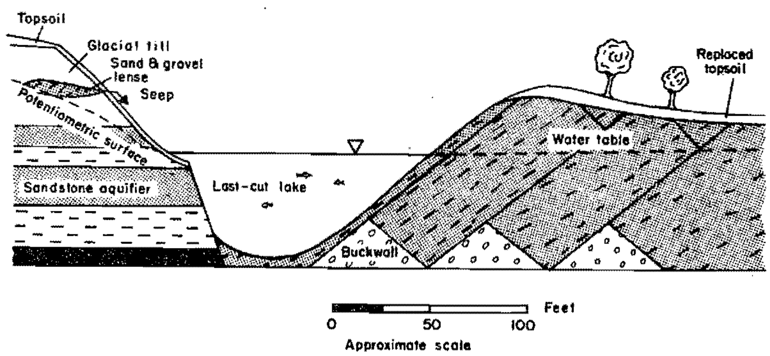
Several techniques have been used to reduce sediment production from surface mined lands:

1. Revegetation: Vegetation reduces erosion by trapping surface runoff and providing flow paths for water to infiltrate into the soil. If local precipitation during the revegetation period is insufficient to establish the plants, however, irrigation is needed to provide supplemental water. The National Academy of Sciences (1974) concluded that, "In areas receiving less than 10 inches of precipitation annually, revegetation can probably only be accomplished with major, sustained inputs of water, fertilizer and management."

More detailed studies, however, indicate that "some success can be expected in the 9 to 10 inch zone under favorable conditions" (U. S. Bureau of Land Management 1978a, p. 173). Aldon and Springfield (1978) conclude



Cross section of active area surface mine in the Midwest.



Cross section of reclaimed area surface mine in the Midwest.

Figure 6.2. Creation of a last cut lake from a surface mining operation (taken from Herring 1978, p. 4-5).

that "supplemental irrigation is necessary for stand establishment where annual precipitation is less than 8 inches" (p. 236).

2. Mechanical treatment of land: Such treatments include ripping the graded overburden, pitting the overburden surface, and contour furrowing. Contour furrowing is designed to break up the long slopes of graded overburden and trap water for vegetation. The storage capacity of furrows may decrease 50 percent in the first five years of use and 75 percent after 10 years (U. S. Bureau of Land Management 1978b).

3. Water harvesting: Water harvesting attempts to cover the soil with paraffin or plastic to trap water for revegetation.

4. Soil amendments: Fertilizer may be added to cast overburden to promote plant growth, and mulch may be added to hold the soil in place for the meantime.

5. Structures: Check dams and retention or detention dams, when properly placed and constructed, may reduce erosion and sediment yield.

Methodology

In order to evaluate the potential for using surface coal mines in Utah to reduce the sediment load to the Colorado River and to enhance water storage in the basin, it was first necessary to:

1. Locate strippable coal reserves in Utah.

2. Estimate present sediment loads of rivers in the study area.

3. Estimate the present sediment yields from lands overlying strippable coal in Utah.

4. Estimate the range of possible sediment yield from surface coal mined lands in Utah.

Location of strippable coal in Utah

Strippable coal is defined as "coal which can be economically extracted using surface mining methods" (U. S. Bureau of Land Management 1975). Because the definition is based on an economic criterion, the location and quantity of strippable coal changes with the economy. For example, coal that is not now economically feasible to mine may become so as the price of coal increases. At current prices, the generally accepted definition of strippable coal is that coal which lies less than 200 feet below the earth's surface in seams five or more feet thick (U. S. Bureau of Land Management 1975).

Strippable coal in Utah. The general location of coal in Utah, less than 500 feet below the ground surface, is shown in Figure 6.3. Because of the relatively thick overburden depths, the National Academy of Sciences (1974) calls it, "the approximate locations of strippable coal deposits within reach of present and probably near future technology for surface mining" (p. 27).

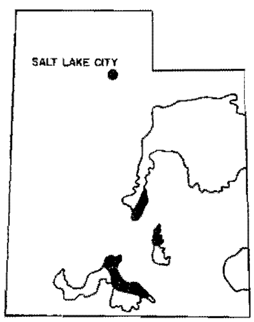


Figure 6.3. Location of strippable coal reserves in Utah (taken from National Academy of Sciences 1974).

The Bureau of Land Management has identified three coal fields in the state that contain significant amounts of strippable coal (Figure 6.4). These areas have been the subject of intensive studies designed to provide baseline information to future coal developers and governmental agencies involved in supervising mined land reclamation projects.

Several companies have filed permits with the Utah Division of Oil, Gas and Mining to conduct surface coal mining operations in the state. Information on the location and size of these proposed operations is contained in Table 6.1. Of these operations, only the Factory Butte mine has produced any coal. The mine is presently closed.

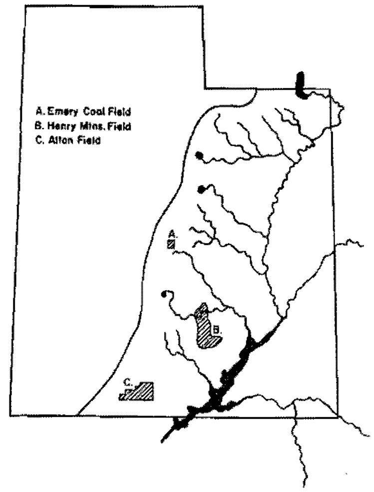


Figure 6.4. Location of surface mine coal fields in Utah (taken from U.S. Bureau of Land Management 1975, 1978).

Estimated sediment yields from rivers in the study area and regions underlain by strippable coal

Sediment yield is defined as "the quantity of sediment transported out of a drainage area or past a given point within it" (Upper Colorado Region 1971, p. 85). Sediment yield rate is the quantity of sediment yield per unit of drainage area per unit of time and is commonly expressed in tons per square mile per year.

The sediment yields of major rivers in the study area were obtained from U. S. Geological Survey records, the Upper Colorado Region study (1971) and the U. S. Bureau of Land Management study of the Henry Mountains coal field (1978a). None of these data concentrate on regions underlain by strippable coal. Estimates for those areas are based on a method developed by the Pacific Southwest Interagency Committee (1968). The method is based on the qualitative ranking of nine factors affecting erosion, including geology, soils, climate, runoff, topography, ground cover, land use, upland and channel erosion, and sediment transport. These factors are described by numerical classes, which when evaluated and combined, result in an estimate of sediment yield. Although not recommended for use in areas of less than 10 square miles, Shown (1970) found that the method provides reasonable estimates for drainage areas as small as one-tenth of a square mile.

Rivers. The annual sediment loads carried by rivers in the study area are shown in Table 6.2. The sediment yield of the Paria River was measured at its confluence with the Colorado River. Only the headwaters

Table 6.1. Present sediment yields in tons/sq. mile/yr. for areas underlain by strippable coal in Utah.

Area or Name	Location	Drainage	Area, sq. mi.	Sediment Load $T/mi^2/yr$	Reference
Emery	T. 22S., R. 6E.	Dirty Devil	0.67[a]	308-770 (1250)	Upper Colorado Region (1971)
Emery (BLM)	See Figure 6.5	Dirty Devil	3.6	308-770 (1250)	U.S. BLM (1979)
Dog Valley	T. 23S., R. 6E.	Dirty Devil	0.34[a]	770-1540 (1250)	Upper Colorado Region (1971)
Shakespeare	T. 36S., R. 2W.	Paria	Not Available	1540-4620 (2250)	" " "
Buck Canyon	T. 18S., R. 23E.	Colorado	0.04[a]	770-1540 (377)	" " "
Factory Butte	T. 27S., R. 9E.	Dirty Devil	1[b]	770-1540 (1250)	" " "
Henry Mtns.	See Figure 6.5	Dirty Devil & Colorado	441 (Total)	308-1540 (1250)	U.S. BLM (1978a)
Alton (USGS)	See Figure 6.5	Paria	12.9	308-1540 (2250)	USGS (1978b)
Alton (USGS)	See Figure 6.5	Paria		> 4620 (2250)	USGS (1978b)
Alton (BLM)	See Figure 6.5	Paria	3.6	154-2310 (2250) See Figure 6.5 for Details	U.S. BLM (1975)

[a]Information from Utah Division of Oil, Gas, and Mining (1979).

[b]Estimated by site visit.

Table 6.2. Suspended sediment discharge, Upper Colorado Region.[a]

Station Number	River and Location	Drainage Area Sq. Mi.	Period	No. Yrs.	Average Annual Runoff Ac-Ft	Average Annual Suspended Sediment Tons	Tons Sq.Mi.	Ac-Ft Sq.Mi.
9-1800	Dolores River near Cisco, Utah	4,580	1951-62	12	506,400	2,254,000	492	0.30
9-1805	Colorado River near Cisco, Utah	24,100	1930-42	13	5,156,000	19,270,000	800	0.50
			1943-52	10	5,726,000	10,300,000	427	0.27
			1953-62	10	4,789,000	9,020,000	375	0.24
			1964-76	12	5,111,000	9,106,000[e]	377	0.24
9-3070	Green River near Ouray, Utah	35,500	1951-62	12	3,984,000	12,620,000[b]	355	0.22
9-3150	Green River at Green River, Utah	40,600	1930-42	13	3,654,000	24,580,000	605	0.37
			1943-62	20	4,244,000	16,920,000	417	0.26
			1951-62	12	4,005,000	15,790,000	389	0.24
			1964-76	12	4,258,000	9,504,000[e]	234	0.14
9-3285	San Rafael River near Green River, Utah	1,690	1949-58	10	111,200	1,480,000	876	0.54
9-3335	Dirty Devil River near Hite, Utah	4,360	1949-58	10	85,100	5,600,000[c]	1,280	0.78
9-0522	Dirty Devil River near Hanksville, Utah	3,500	1946-48	3	2,835	4,375,000[d]	1,250	0.81
9-3395	Escalante River near Escalante, Utah	1,770	1951-55	5	61,700	1,757,000	993	0.61
9-3795	San Juan River near Bluff, Utah	23,000	1930-42	13	1,972,000	46,340,000	2,010	1.24
			1943-52	10	1,666,000	19,090,000	830	0.52
			1953-62	10	1,492,000	16,200,000	704	0.45
9-3800	Colorado River at Lees Ferry, Arizona	107,900	1930-42	13	11,330,000	133,700,000	1,240	0.77
			1943-52	10	12,500,000	80,000,000[f]	742	0.45
			1953-62	10	9,980,000	56,320,000	522	0.32
9-3820	Paria River at Lees Ferry, Arizona	1,570	1948-65	18	17,790	3,536,000	2,250	1.41

[a]Unless otherwise noted, data are from Upper Colorado Region (1971).

[b]Flaming Gorge Dam closed November 1, 1962.

[c]Partly estimated.

[d]Records from U.S. Bureau of Land Management (1978a).

[e]Records from U.S. Geological Survey.

[f]Glen Canyon Dam closed March 13, 1963.

of the river are shown in the study area (Figure 1.3).

Regions underlain by strippable coal. Table 6.1 contains the available annual sediment yield data for specific areas of Utah underlain by strippable coal. The figures in parentheses in the sediment yield column are the sediment yield values of the parent river watershed. Detailed sediment yield values from the Alton coal field study area were available and are presented in Figure 6.5.

Estimated sediment yields from surface mined areas

No recorded data exist which measure the sediment yield from surface mined lands in Utah, and only three published estimates, all for the Alton coal field, were available for this report. Each of these three cases will now be discussed.

Estimates based on the Southern Utah Regional Study. The estimate of sediment yield from the 12.9-square mile disturbed area of the Alton coal field (from the Draft Environmental Statement of Southern Utah Coal Development) is shown in Table 6.3. In making the estimates, it was stated,

> On-site erosion estimates by water are based on the universal soil loss equation described by the USDA, Soil Conservation Service. The maximum rate of erosion was determined for a fresh spoil pile composed mostly of clay-shale material, with a slope length of 120 feet and a gradient of 60 percent. Wind erosion estimates are based on the system described by the USDA Soil Conservation Service (p. IV-5).

Thus, the estimate shown in Table 6.3 is based on water and wind erosion from recently placed ungraded overburden. Concerning erosion from the overburden after reclamation, which is deemed possible by the statement, the study concludes:

> After reclamation, soil erosion rates should be lower than under natural conditions over much of the area, owing to reduced slopes, installation of erosion control structures, mulching and reestablishment of vegetation (p. IV-5).

Table 6.3. Estimates of sediment yield from surface coal mined land near Alton, Utah.

Sediment Yield T/mi^2/yr.	Reference
6416 - 7700	U.S. Geological Survey (1978f)
> 4620	U.S. Geological Survey (1979g)

Estimates based on the Alton site specific study. A companion study estimates sediment yield from the proposed surface mine site at Alton, also presented in Table 6.3. The estimates, based on the Pacific Southwest Interagency Committee system, are for ungraded overburden. This study also comments on the qualitative effects of shaping and regrading the overburden: "Shaping and regrading the spoil would leave some areas more gently sloping than the original contour which probably would reduce erosion and create a more manageable land form" (U. S. Geological Study, 1978g).

Estimates based on the Alton study site. Estimates of post-mining sediment yield from the Alton study site of the U. S. Bureau of Land Management (Figure 6.5) are contained in Table 6.4. These estimates are also based on the Pacific Southwest Interagency Committee method for estimating sediment yield. Values are given for different reclamation treatments and for varying overburden slopes and composition.

Results

This chapter assesses the potential for using surface coal mines in Utah to: 1) Control the sediment load to the Colorado River, and 2) enhance water storage in the basin.

Contribution of sediment from surface mined lands to the Colorado River

Table 6.5 contains sample calculations showing how the contribution of sediment from surface coal mined lands in Utah to the Colorado River was computed. The area described by "all others" contains the permit areas shown in Table 6.1 and the 50 percent of the Henry Mountains coal field area which was assumed to be disturbed by surface mining. The assumed pre-mining sediment yield values in column 2 represent the lowest estimated yield from the contributing areas, while post-mining sediment yields were based on worst possible conditions, assuming an 80-100 percent newly created overburden slope. The final percentage represents the net annual change in the sediment yields from surface coal mined lands in Utah to the Colorado River at Lee Ferry, Arizona, after mining has occurred.

Sediment yields for varying overburden materials, slopes, and reclamation treatments are shown in Table 6.6 and are taken from the U. S. Bureau of Land Management (1975, p. 104).

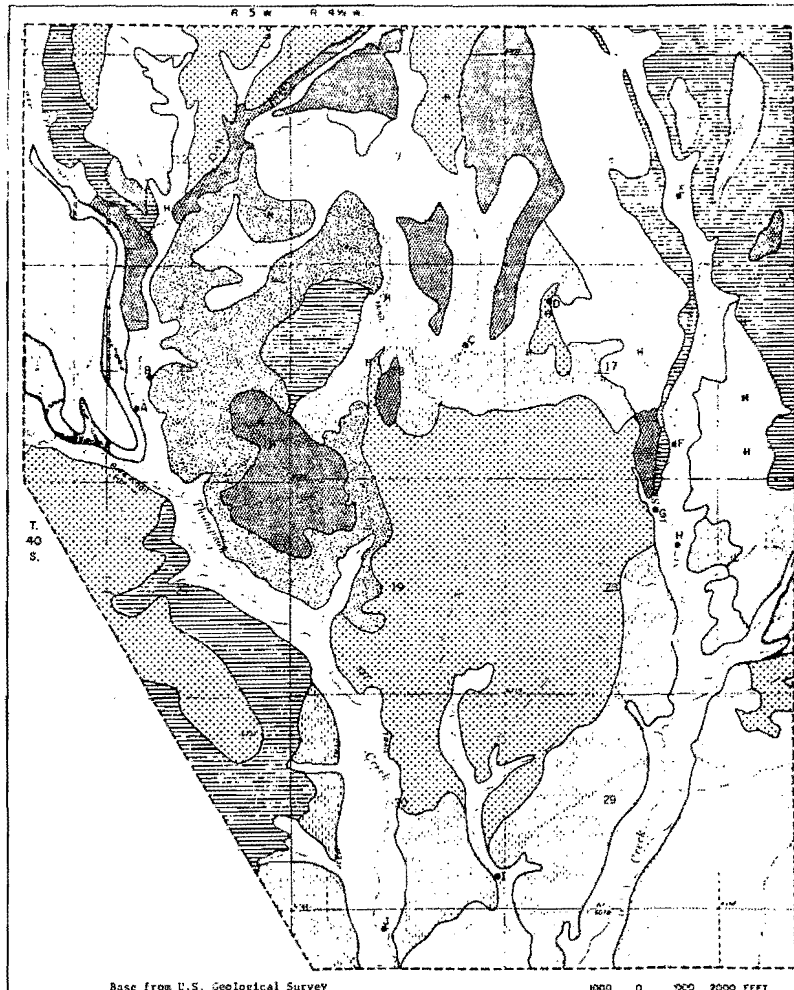
The increase in sediment shown in Table 6.5 represents the maximum possible contribu-

EXPLANATION

Annual source-area sediment yields (acre-ft/mi²)	Topography	Slope: Range percent	Slope: Mean percent	Relative drainage density	Surficial materials
.1- .3	a. Pediments	4- 8	5	Low	Stony soils developed in outwash deposits
	b. Mesas	4- 8	5	Low	Sandy and clayey soils
	c. Revegetated bottomlands	4	4	Low	Coarse- to medium-textured alluvium
.2- .4	a. Bottomlands	2- 4	3	Low	Coarse- to medium-textured alluvium
	b. Dissected pediments and mesas	3-15	7	Low to medium	Sand and clayey soils, some clinker
.3- .5	a. Hill-and-valley	8-33	18	Low to medium	Sandy, silty and clayey soils, some clinker
	b. Hillslopes	7- 9	8	Low	Sandy and silty soils
.4- .6	a. Hill-and-valley	8-50	21	Low to medium	Sandy, silty and clayey soils
	b. Hummocky	22-33	25	Medium	Clinker, sandy and clayey soils
	c. Upland alluvial	8-17	12	Medium	Sandy clay soils
.6- .8	a. Hill-and-valley	11-40	22	Medium to high	Sandy and clayey soils
.8-1.0	a. Steep valley-side slopes	36-40	38	Medium	Clayey- and medium-textured soils
1.0-1.2	a. Steep hill-and-valley	20-50	35	Medium to high	Clayey and sandy soils
1.2-1.5	a. Steep hill-and-valley, few landslides	8-55	35	High	Sandy and silty soils

● A Locations of the outlet of drainage basins for which sediment-yield estimates were made and the points at which peak flow estimates were made.

H Locations of headcuts in channels.



Base from U.S. Geological Survey
Bald Knoll and Skutumpah Creek 7½ minute Quadrangles

Estimated source-area sediment yields, locations of points on channels to which basin sediment yields apply and where peak discharge estimates were made, and locations of headcuts on the Alton Coal Field Study Site, Utah

Figure 6.5. Sediment yield estimates from Alton surface mine study site (taken from U.S. Bureau of Land Management 1975, p. 100).

Table 6.4. Estimates of annual sediment yield from presumed overburden areas before, during, and after rehabilitation for various rock types, slope gradients, and amounts of bare soil (taken from U.S. Bureau of Reclamation, 1975, p. 104).

	Ungraded Overburden Banks	Graded Overburden			Rehabilitated Overburden during Establishment of Perennial Vegetation[a]			Rehabilitated Overburden after Establishment of Vegetation[b]		
Slope (percent)	80-100	0-5	15	30	0-5	15	30	0-5	15	30
Bare Soil (percent)										
Shale Material	100		100		50	60	70	30	40	50
Sandstone and Shale Material	75 (rock, 25)		75 (rock, 25)		25	35	45	15	25	35
Sediment Yield (acre-ft/mi^2)										
Shale Material	2.5-5.0	0.3	0.5	0.9	0.2	0.3	0.5	0.2	0.3	0.5
Sandstone and Shale Material	1.5-2.0	0.2	0.3	0.6	0	0.2	0.3	0.1	0.2	0.4

[a]Assumed that overburden would be contour furrowed or pitted to reduce runoff and erosion and enhance establishment of the seeded perennial grasses and shrubs. Assumed that the area would be protected from grazing during this 5-year rehabilitation period.

[b]Moderate intensity grazing was assumed when making these estimates.

Table 6.5. Example of procedure used to estimate net contribution of sediment from surface coal mined lands in Utah to Colorado River.

Site	(1) Area mi^2	(2) Assumed Pre-Mining Sediment Yield T/mi^2/yr	(3) Assumed Post-Mining Sediment Yield T/mi^2/yr		Total Tonnage Contribution: Tonnage Pre-Mining (1 x 2)	Total Tonnage Contribution: Contribution Post-Mining (1 x 3)
Alton	12.9	154	7,700		2,000	99,500
All Others	225	308	7,700		69,500	1,732,500
				Total:	71,500	1,832,000

Difference: 1,832,000 - 71,500 = 1,760,500 tons/yr

$$\text{Contribution} = \frac{\text{Difference}}{\text{Total Colorado River Sediment Load}} \times 100 = \frac{1{,}760{,}500}{56{,}323{,}800} = 3.1\%$$

tion of sediment to the Colorado River from surface mined lands in Utah. The figure was calculated assuming:

1. Fifty percent of the Henry Mountains coal field would be disturbed by surface mining since no better information was available.

2. The overburden is composed entirely of highly erodible shale. While not likely true, this assumption was used to reach a maximum upper limit in sediment production.

3. Overburden slopes approach 80-100 percent.

Grading to reduce the slope to 15 percent reduces the sediment contribution to the Colorado River from 3.1 to 0.2 percent, still assuming that the overburden is composed completely of shale. A sandstone and shale overburden graded to 15 percent produces essentially the same volume of sediment as natural conditions.

Rehabilitating overburden with contour furrows and vegetation for 5 years further reduces sediment production 0.17 percent. If moderate grazing is allowed after re-vegetation has occurred, sedimentation rates increase slightly.

Table 6.6. Possible range of contribution of sediment from surface mined lands in Utah to Colorado River.

	Ungraded Overburden Banks	Graded Overburden			Rehabilitated Overburden during Establishment of Perennial Vegetation[a]			Rehabilitated Overburden after Establishment of Vegetation[a]		
Slope (percent)	80-100	0-5	15	30	0-5	15	30	0-5	15	30
Post Mining Sediment Yield ($tons/mi^2/yr$)[b] Shale Material	3850-7700	460	770	1385	308	460	770	308	460	770
Sandstone and Shale Material	2310-3080	308	460	925	0	308	460	154	308	615
Annual Tonnage,[c] Thousands of Tons Shale Material	905-1810	108	181	325	72	108	181	72	108	181
Sandstone and Shale Material	543-725	72	108	217	0	72	108	36	72	145
Change in Sediment Yield of Colorado River[d] (percent) Shale Material	+1.5-+3.1	+0.07	+0.2	+0.5	-	+0.07	+0.2	-	+0.07	+0.2
Sandstone and Shale Material	+0.8-+1.2	-	+0.07	+0.3	-0.1	-	+0.07	-0.06	-	+0.1

[a]See Table 6.4 for further explanation.

[b]Based on estimates given on page 104, U.S. Bureau of Land Management (1975).

[c]Based on a composite area of 235 square miles.

[d]See Table 6.5 for explanation of how calculated.

No sediment yield estimates were available for surface mined lands where the last cut pit was left open. The highest annual sediment production rate, 7,700 tons per square mile, would require only 5 acre feet of reservoir storage each year per square mile of disturbed land. Based on this maximum rate of production, a last cut pit measuring 3,000 feet long and 100 feet wide and 100 feet deep could contain the sediment from about 13 square miles of surface mined land for 10 years. The proposed surface mine at Alton would disturb a maximum of 13 square miles. Therefore, over a period of average runoff conditions, sediment production from such an area would be negligible for 10 years, assuming that the last cut pit collected all the runoff from the disturbed area. After 10 years, sediment production from the disturbed land should have decreased significantly due to natural rehabilitation.

Enhancement of water storage using surface mines

The evaluation of using surface coal mined lands to store water in the Colorado Basin follows. The analysis assumes that the storage would be in the last cut pit, left open to collect water from precipitation, diverted surface channels, and groundwater interception.

Storing on-site precipitation. Mean annual precipitation, potential evapotranspiration and water yield values for areas underlain by strippable coal are contained in Table 6.7. Annual potential evapotranspiration in all cases exceeds annual precipitation. Even winter precipitation, usually snow, would not be expected to accumulate. Summertime precipitation from thunderstorms could produce runoff to the open pit for storage, but such storage would be only temporary, as summer evaporation rates are very high.

Surface stream storage. Water from surface streams could be diverted into the pits, but this would have to be coordinated with prior downstream water rights. Probably, the channeling of surface streams into the last cut pit to create storage would be limited to ephemeral streams responding to summer thunderstorms. Such runoff, however,

Table 6.7. Annual precipitation, potential evapotranspiration, and water yield for areas underlain by strippable coal in Utah (data from Jeppson et al. 1968).

Area or Name	Location	Area, mi^2	Precipitation, in. Annual	Precipitation, in. May-Sept.	Annual Potential Evapotranspiration, in.	Annual Water Yield, in.
Emery	T. 22S., R. 6E.	0.67	7.2	< 4	24-27	< 1
Dog Valley	T. 23S., R. 6E.	0.34	7.2	< 4	24-27	< 1
Shakespeare	T. 36S., R. 2W.	Not Avail.	16	6	18-24	1.0
Buck Canyon	T. 18S., R. 23E.	0.04	9	3.5	27-30	< 1
Factory Butte	T. 27S., R. 9E.	1.0	7	3	27-30	< 1
Henry Mountains	See Figure 6.5	441	12	5	24-27	1.0
Alton #1	See Figure 6.5	12.9	16	6	21-24	1.0
Alton #2	See Figure 6.5	3.6	16	6	21-24	1.0

could create considerable storage for a short time.

Storing intercepted groundwater. The Emery surface mine site is the only one in Utah expected to intercept a groundwater aquifer (see Chapter II for discussion). The aquifer, confined locally in the Ferron sandstone, drains into Quitchupah Creek and Christiansen Wash immediately southeast of the proposed mine (see Figure 2.3). Consolidation Coal Company (1978) states, "the void created by the removal of the coal will be desirable because it will provide substantial storage for groundwater" (p. 38).

It has been shown (Chapter III) that groundwater in the Ferron sandstone has TDS levels of approximately 1,000 parts per million, about one third that of the streams receiving flow from the aquifer. Interception and storage of groundwater, then, could provide usable volumes of irrigation water to local agriculture.

CHAPTER VII

CONTAINMENT PONDS

The sediment and salts contained in water flows from coal mines can be trapped in containment ponds. If it is desired to contain all the salt, the pond must be large enough to provide total containment and have a water proof liner to prevent infiltration. This type of pond will hold the salts but remove all of the water from the system too. If it is desirable to remove only the sediment, the containment pond becomes a sediment pond and/or a filter. The function of the pond depends on the desired flow path for the water. If the water is to enter the groundwater system, the pond will act as a settling basin and a filter to remove the sediment as the water infiltrates. If the desired flow path is to a surface stream, the pond will be a settling pond that overflows through an elevated exit channel. A pond can be designed to perform either function.

The selection of the surface or underground flow path is based on the potential salt pickup along each path. It is possible for water following the underground flow path to pick up additional salts while water following the surface path would hold salts at the mine outflow level, or vice versa. The choice would obviously be to minimize the salt load to the surface stream. If the water intercepted by the mine is of good quality and the groundwater subsequently enters salt bearing shales, the mine waters should be delivered immediately to the surface stream to minimize salt pickup. Opposite conditions would dictate the opposite decision.

The pond can be designed to detain either sediment or salt, or both sediment and salt. A pond designed to function as a total containment system will minimize seepage to groundwater and be sized for sufficient evaporation to return the inflow to the atmosphere. A total containment pond will require a liner which, if made of clay or soil, will follow the Darcy Equation:

$$Q = kiA \quad \quad (7.1)$$

in which

- Q = the flow through the liner
- k = the coefficient of permeability
- i = the hydraulic gradient, which equals the headloss, h, divided by the length of flow, L
- A = pond area

The water stored in the pond is determined from the continuity equation and can be expressed as:

$$S = I - O \quad \quad (7.2)$$

in which

- S = the storage in the pond
- I = the accumulated inflow to the pond
- O = the accumulated outflow from the pond

The inflow to the pond comes from the mine operation. The outflow can be separated into two components, evaporation and seepage. Evaporation is the return of water to the atmosphere. The evaporation rate varies during the year in a pattern that can be measured by use of a Class A evaporation pan. The actual evaporation from lakes can be related to the pan evaporation by multiplying by a coefficient, normally taken on an annual basis to be 0.7. However, the accumulation of salinity in a containment pond reduces the evaporation rate. The work done to estimate the effect of salinity on evaporation from the Great Salt Lake can be used to estimate evaporation from containment ponds in Utah. Estimates for the Great Salt Lake were made by Adams (1934), Jones (1933), and Jones (1976). Each author used a different equation to determine a factor for adjusting fresh water evaporation to various salinity concentrations. The equation which fits Adams' data was selected for this study since it is the most conservative of the sediment content may also suppress containment pond evaporation. The equation is:

$$R = 1. - 0.01C \quad \quad (7.3)$$

in which

- C = the average salt concentration in percent for the time period of interest and is equal to or less than the saturation level of 30 percent
- R = the evaporation ratio of salt water to fresh water at the concentration of C and for the same time period

Table 7.1 shows the ratio values for various concentrations given by the three authors. The concentration ratio times the

Table 7.1. Ratio of brine solution to fresh water evaporation rate as proposed by three authors for various levels of brine concentration.

Salt Content in Percent	Adams (1934)	Jones (1934)	Jones, Craig (1976)
14	0.86	0.88	0.90
15.2	0.85	0.87	0.89
16.5	0.84	0.86	0.88
18.1	0.82	0.85	0.87
20.2	0.80	0.83	0.86
22.2	0.78	0.82	0.85
25.3	0.75	0.79	0.83
29.0	0.71	0.76	0.81
30.0	0.70	0.75	0.80
	$R = 1 - 0.01C$	$R = 1 - 0.00833C$	$R = 1 - 0.778\left(\frac{C}{100 + 0.63C}\right)$

in which

R = the ratio of the brine solution of fresh water evaporation rates

C = the concentration of the brine solution in percent

evaporation for fresh water estimates the evaporation for salt water at the given salinity concentration.

There are many equations to predict the evaporation of fresh water from ponds and lakes. Many of the equations require data that are not available at most locations throughout the state. Therefore, it was decided to use pan evaporation and adjust it to predict the pond evaporation. Combining the pan evaporation and the salinity correction gives the equation for evaporation.

$$E_v = E_{vp} F (1. - 0.01C) \quad . \quad . \quad . \quad (7.4)$$

in which

E_v = the evaporation from the pond in inches

E_{vp} = the measured Class A pan evaporation in inches

F = the coefficient to correct pan to lake evaporation, usually = 0.7

Any other equation can be used to calculate fresh water evaporation if the data are available. To determine the total evaporation from the pond in acre-feet, the evaporation in inches must be multiplied by the average area, in acres, of the pond surface during the chosen time period.

$$O_e = E_{vp} F (1. - 0.01C) \frac{A_e}{12} \quad . \quad . \quad (7.5)$$

in which

O_e = the evaporation outflow in acre-feet per time period

A_e = the area of the pond surface, in acres, during the time period

A pond also loses water by seepage. The driving force is the total depth of water in the pond, and it is resisted by the pond liner and the soil deposited above it. The assumption is made that the pond is placed upon a material that is significantly more porous than the liner, and so the material under the liner does not support saturated flow. It is also assumed that the water table is sufficiently far below the pond that a water dome does not build to the pond bottom from the water table. The liner and the deposited material are sufficiently different to require treatment as a double layer with one layer changing with time and the other layer, the liner, remaining the same. The sum of the head loss through each layer will be equal to the depth of water in the pond. The head loss through the sediment is:

$$h_s = \frac{QL_s}{k_s A} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7.6)$$

in which

k_s = the coefficient of hydraulic conductivity of the settled layer

L_s = the depth of the settled layer

h_s = the head loss through the settled layer

The head loss through the pond liner will be described by the equation:

$$h_l = \frac{QL_l}{Ak_l} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7.7)$$

in which

The subscript l indicates parameters for the liner for the same parameters used for the settled sediment layer.

The sum of the two head losses will be equal to the total head of water in the pond.

$$h = h_s + h_1$$

$$= \frac{Q}{A}\left(\frac{L_s}{k_s} + \frac{L_1}{k_1}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad (7.8)$$

The seepage flow through the bottom of the pond can be calculated from the above equation by solving for Q:

$$O_s = \frac{h\ A}{\frac{L_s}{k_s} + \frac{L_1}{k_1}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (7.9)$$

in which

O_s = the seepage outflow from the pond

Calculation of the seepage outflow requires the determination of both the area of the pond and the depth of water in the pond. Since the slope of the pond banks means that a change in the depth of water causes a change in the area of the water surface in the pond, these parameters must be determined iteratively. It must also be kept in mind that the value of L_s will change as additional sediment settles to the bottom.

Assuming that the configuration of the pond is rectangular with a flat bottom and sloping sides, the total storage in the pond is:

$$Q = \frac{ab + \left(a + \frac{2h}{s}\right)\left(b + \frac{2h}{s}\right)}{2 \times 43560}\ h \quad . \quad . \quad . \quad (7.10)$$

in which

a & b = the dimensions of the bottom of the pond in feet

h = the depth of water above the pond bottom in feet

s = the slope of the pond embankment, for example, for a 2:1 slope, s = 0.5

The surface area of the pond for evaporation is:

$$A_e = \left(a + \frac{2h}{s}\right)\left(b + \frac{2h}{s}\right)\Big/43560 \quad . \quad . \quad (7.11)$$

The equivalent area of the embankment for seepage purposes is equal to one-half of the area covered by water. This is so because the water depth on the bank varies from zero to the water depth at the pond bottom for an average depth of one-half of the total water depth. Since the seepage equation is linear, the fraction can be applied to either the area or the water depth. In this case the area was selected. The equivalent area is:

$$A_s = \left(ab + \frac{ah}{s} + \frac{bh}{s} + \frac{2h^2}{s^2}\right)\Big/43560 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7.12)$$

The equations are now available to calculate the outflow due to evaporation and seepage based on an average area and water depth for the time period selected. Solution is accomplished by beginning with the total storage at the beginning of the period and adding the measured inflow. The total storage is used in the storage equation to determine the corresponding water depth. The evaporation for the time period is subtracted from the water depth to obtain the first approximation. This depth is used to calculate the evaporation and seepage outflows which are subtracted from the storage, plus inflow, to obtain a new estimate of final storage. The calculated storage is used to calculate a new water depth which is used to calculate new losses, and the procedure is repeated. The number of iterations is determined by the convergence of the estimated and calculated water depth. Three or four iterations usually are adequate. The final average water depth gives the calculated losses to the groundwater which are used to determine the impacts of the total containment pond on the downstream portion of the system.

In applying the equations for a given time period, both the pond surface area and the water depth must be the averages for the time period. These equations can be used both to design the containment pond or to determine the impacts of the pond on the groundwater system. A step sequence can be formulated to follow in checking the performance of a designed pond. These steps are:

1. Beginning with an initial pond storage, add the measured inflow plus precipitation.

2. From the storage equation, iteratively calculate the required water depth at the storage value calculated in 1. A storage-depth curve can be made for any pond to facilitate this step.

3. Subtract from the water depth calculated in 2, the pond evaporation depth.

4. Use the water depth calculated in 3 to calculate evaporation and seepage losses for the time period.

5. Subtract these from the total storage in 1 and average the beginning and ending storages to get an average storage.

6. Determine a new depth and use this depth beginning in step 4.

7. When the depth in 6 is essentially the same for two calculations or iterations, the average pond depth for the period is established. If there is no convergence to a depth in step 6, the new average depth and the previous average depth can be averaged for a new trial depth.

The following equations are those to be used with the indicated steps of the above procedure. To facilitate the application of this procedure, a program was developed for the TI-59 programmable calculator and is included in this report as Appendix B.

1. $S_f = S_o + I + PPT$

2. $S_f = \dfrac{ab + \frac{ah}{s} + \frac{bh}{s} + \frac{2h}{s^2}}{43560} h$

3. $h = h_f - \dfrac{Evap\ (1. - 0.01C)\ (m - 0.7)}{12}$

4. $\dfrac{h_f + h_o}{2} = h_e = h_s$

$$A_e = \frac{\left(a + \frac{2h_e}{s}\right)\left(b + \frac{2h_e}{s}\right)}{43560}$$

$$A_s = \frac{\left(ab + \frac{ah_s}{s} + \frac{bh_s}{s} + \frac{2h_s^2}{s^2}\right)}{43560}$$

$$O_c = \frac{Evp\ (1. - 0.01C)\ m\ A_e}{12}$$

$$Q_s = \frac{h_s\ A_s}{\frac{L_s}{K_s} + \frac{L_\ell}{L_\ell}}$$

5. $S_f = S_o + I + PPT - Q_e - Q_s$

6. $S = \dfrac{ab + \ a + \frac{2h}{s} \quad b + \frac{2h}{s}}{2 \times 43560} h,$ Iterate for h

7. $\dfrac{h_i + h_{i-1}}{Z} = h_{i+1}$

The precipitation is measured in inches but must be converted to acre-feet. The area included for precipitation catchment is that to the top of the embankment, not just to the water depth.

The importance of the proper construction of the containment pond can be illustrated by some preliminary calculations. If the hydraulic gradient can be assumed to equal 1, that is the total head loss equals the length of the flow path downward through the bottom sediment and liner, the seepage is significant unless the coefficient of permeability is less than 10^{-6} cm/min. Since most soils in coal areas are more permeable than that, the total containment pond must be lined. A 6-inch layer of good clay with a permeability coefficient less than 10^{-8} cm/min will provide sufficient resistance to flow to make the seepage loss insignificant. Unless the pond is constructed in a medium to good clay, the seepage resistance will not be adequate. A good clay liner with a permeability coefficient of 10^{-12} cm/min could be thinner if its mechanical application could be sufficiently controlled such that the proper thickness is achieved in all places over the pond bottom. If the sediments that are to be deposited in the pond are very fine, they will add to the flow resistance provided by the liner and may be accounted for in the calculations.

The salinity concentration determined at the end of each time period is used as the salinity concentration for the next time period calculation. Added salt comes from the inflow while lost salt is accounted for in the seepage flow. The evaporation of water has a concentrating effect. The equation to determine the salinity concentration is:

$$C = \frac{S_o C_o + IC_i - O_s C_s}{S_o + I + PPT - O_s - O_e} \quad . \quad . \quad . \quad (7.13)$$

in which

C = concentration of the pond at the end of the time period in tons per acre-foot

$S_o C_o$ = storage and concentration in the pond at the beginning of the time period

IC_i = inflow and concentration of the inflow to the pond during the time period

$O_s C_s$ = seepage outflow and concentration for the time period. These combinations are equal to the total salt in tons for each of the processes.

The sediment added to the pond can be calculated in a like manner by the equation:

$$S_a = IS_{\%v}$$

in which

S_a = sediment added during the time period

$S\%_v$ = sediment concentration by volume of the inflow

The depth of sediment added is determined by the total sediment load divided by the average area for the time period, which is the evaporation area A_e:

$$D_{sa} = S_a/A_e \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7.14)$$

in which

D_{sa} = depth of the sediment added during the time period

The sediment depth at the end of the time period also is used as the depth of sediment for the calculations over the succeeding time period. In cases where the depth is insignificant for each time period, the sediment addition can be calculated at the end of each year.

The impacts of the seepage from the containment pond are determined by defining the subsequent flow path and the geology of that flow path. Whether the salt pickup will increase or decrease is estimated from these considerations. A well lined containment pond has an insignificant seepage component but wastes water to the atmosphere. Hydrologic opportunities should not be bypassed as a result of regulations that do not consider each case for its individual merits or demerits.

CHAPTER VIII

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The purpose of this study was to assess the potential of realizing hydrologic benefits from coal mining in the State of Utah and to identify management practices that would best develop these benefits. The assessment investigated opportunities to use: 1) underground coal mines to tap groundwater supplies, reduce the salt load to the Colorado River, and store water in abandoned mines and 2) surface mined areas to reduce sediment loads and store water. This chapter summarizes the results and makes recommendations based on the overall study.

Summary of Results

The potential for using underground coal mines to tap groundwater supplies

1. Steady state groundwater interception by underground coal mines in the Book Cliffs coal field should be approximately 2.5 inches per year per unit area of mine development.

2. Except near faults in the Wasatch Plateau coal field, annual steady state groundwater interception by underground coal mines may approach 3 inches at lower elevations and 4 or more inches at higher elevations per unit area of mine development.

3. Mining in the Ferron sandstone member east of Joe's Valley fault and west of Quitchupah Creek in the Emery coal field should intercept groundwater at the relatively high rate of up to 22 inches per year per unit area of mine development.

4. The underground coal mines in central Utah intercept groundwater at a rate which exceeds in-mine water demand. Water discharged from the mines is available for further development.

5. Mining near perennial streams is likely to intersect a local groundwater table and produce large volumes of water. Away from perennial streams, intercepted aquifers are more likely to drain, gradually reducing groundwater interception rates.

6. The volume of groundwater intercepted in mines not located in saturated aquifers decreases with time until a steady state condition exists, representative of deep percolation to the mine from surface precipitation.

7. It would be advantageous, particularly when more water is likely to be intercepted in the first years of mine development, to develop and use the intercepted groundwater. Volumes are likely to be large enough to meet the demands of the population brought into the area by mining activity. The intercepted water could satisfy the immediate water needs of the local community and, even if insufficient for the long run, give them more time to develop long term water sources. As coal production increases, deep percolation may continue to represent a significant contribution to municipal water supply, as suggested in the case of the Hiawatha mine.

The potential for using underground coal mines to reduce the salt load to the Colorado River

1. Groundwater along the flow path from the central Utah coal fields to the Colorado River is almost universally more saline than the waters of the river.

2. Site specific studies of underground coal mines in central Utah show that the TDS concentration of intercepted groundwater does not significantly increase while flowing through the mine except where such water travels long distances through mined out areas before being discharged.

3. If the mining intercepts groundwater upstream of a salt-laden aquifer, mines may decrease the salinity of the Colorado River by intercepting groundwater before it percolates through saline formations and deteriorates in quality.

4. Nine of the 13 mines where TDS measurements were available discharge groundwater with TDS concentrations lower than those of the Colorado River.

5. Simple discharge of groundwater into surface channels may deteriorate TDS levels to those of the receiving channels. If economically feasible, the water should be conveyed past salt bearing formations to avoid high salt pickup.

6. A quantitative study comparing salt loadings between underground and streamflow rates would be necessary before coming to a conclusion on whether or not underground coal mining in central Utah increases the salinity of the Colorado River.

7. Each mine represents a specific case in the way local geology, topography and water resources affect water quality. Each location has its own characteristics with respect to salt loading in downstream aquifers and surface channels. Therefore, each mining operation should be examined individually in determining an appropriate water management policy.

8. More data are needed on groundwater and related salinity conditions in the coal field areas to have a sound basis for formulating mine water measurement policy. Specifically, data are needed on:

a. The groundwater flow path from the coal fields to the Colorado River.

b. Flow and quality conditions in aquifers in the vicinity of coal mines.

c. Salt loading conditions in the streams between the coal fields and the river.

9. Attempts should be made to locate points of groundwater inflow to streams in the vicinity of proposed underground coal mines. Such data would more definitely establish the salinity of groundwater if it were not intercepted by coal mines, and may further support the hypothesis that some coal mines can decrease the salt load to the Colorado River.

10. Attempts should be made to estimate more accurately the travel time of groundwater from the coal fields to the Colorado River. The limited tests performed to date suggest a travel time of up to 30,000 years. If such is the case, short-term impacts from mining on the Colorado River would be negligible.

11. In some cases, the best policy may be to contain or to return intercepted groundwater. Such cases arise where:

a. TDS levels of intercepted groundwater prevent its beneficial use.

b. TDS concentrations of discharged minewater flowing to the Colorado River through surface channels are higher than what they would be if those same waters entered the Colorado through groundwater aquifers.

The potential for using abandoned underground coal mines to store water

1. The potential for using abandoned underground coal mines to store water depends on a) the adequacy of the storage when groundwater inflows and outflows are in equilibrium, b) the cost of required underground pumps and pipe systems, c) the cost of controlling underground leaks from residual cracks in the reservoir, d) the development of storage methods for use with longwall mining technology, and e) the groundwater pollution potential and the associated cost of any required treatment.

2. If these engineering problems are successfully solved, a) abandoned underground coal mines may provide valuable storage space for much needed water in central Utah, and b) such underground storage reservoirs could prevent the large evaporative losses of water while providing water of uniform temperature and chemical content for beneficial use.

Potential effects of subsurface mining on water resources

Underground coal mining operations may affect local water resources in the following ways:

1. Mines may intercept isolated perched aquifers and make previously inaccessible water available for beneficial use.

2. Mines may reduce springflows by draining or intercepting contributing perched aquifers and deep percolation.

3. Mines intercepting and moving groundwater from one watershed to another increase streamflow in the discharge watershed while decreasing streamflow below the area of interception.

4. Effluent streams may be changed to influent streams where mines drain local groundwater tables below perennial streambed elevations.

5. Surface cracking and subsidence induced by mining operations may divert surface water into the ground where it would percolate to the mine or be discharged to existing or newly created springs.

6. Proper mine management can minimize the pollution of nearby groundwaters by the mining.

7. Faulting has a significant effect on groundwater flow paths, and these can be substantially altered when the mined seams cross fault zones. Seismic investigations should be conducted in advance of mining development to look for probable changes to the hydrologic regime.

The potential for using surface mined lands to reduce the sediment load to the Colorado River

1. The maximum possible increase in sediment load to the Colorado River from surface coal mining is 3.1 percent.

2. Under normal meteorological conditions, the minimum regrading effort is the best for reducing sediment production from surface coal mined lands to pre-mining levels. This is because not grading the cast overburden a) reduces slope length (erosion

is directly related to slope length), and b) creates a network of small sediment basins over the area and thus reduces surface runoff and sediment outflow from the land surface.

3. Use of the last-cut pit as a sedimentation basin could eliminate sediment transport from surface mined lands for 10 years or more. Natural rehabilitation occurring during this period could lower sediment yields from the mined area after the effective life of the sedimentation basin has been reached. Further research is needed to develop the method.

4. The decrease in the sediment load to the Colorado River achieved by contour furrowing and protecting graded overburden from grazing for 5 years is insignificant.

The potential for using surface-mined lands for water storage

1. Insignificant storage would be collected in last-cut pits from on-site precipitation.

2. The storage accrued in last-cut pits that receive inflow from diverted ephemeral streams may be of temporary use, but should not be depended upon as a primary source of water.

3. Surface coal mines which intersect groundwater aquifers beneficially use the last-cut pit to collect intercepted water. Such water may be useful for irrigation or other purposes.

Recommendations

Mathematical models in groundwater flow analysis

In order to develop the capability needed to evaluate the relationship between coal mining and associated hydrologic opportunities, it is recommended that stochastic groundwater flow models of the central Utah coal field aquifers be developed.

Deterministic models traditionally have been applied in groundwater flow analyses. Only recently has consideration been given to the application of stochastic methods that can deal with the fact that flow through non-uniform or heterogeneous porous media is basically stochastic in nature. In deterministic flow models, parameters are assumed to be constant. For realistic assessments of groundwater flows in and around Utah coal fields, spatial differences in parameter estimates need to be considered. In the stochastic approach, hydrologic parameters, such as hydraulic conductivity, soil compressibility, and porosity, are represented by probability distributions. A further discussion on the use of stochastic methods in groundwater flow analysis is contained in Appendix C.

Fieldwork

The results of this study were based on secondary data collected from literature, government, and the coal mining industry. In many cases, site specific geologic and hydrologic data were not available. In order to be more exact in defining the effects that coal mining would have on the hydrologic environment, the following fieldwork in the regions surrounding existing and proposed coal mines would be useful:

1. Locate all streams, springs, seeps, wells, lakes and ponds.

2. Monitor the water quality and quantity of all sources of water before mining commences and throughout the life of the operation.

3. Monitor the quality and quantity of all mine discharges.

4. Locate groundwater aquifers by inspection of test hole records and/or other borings and by inference from the regional geology.

5. Record piezometric levels of wells.

6. Locate and record all faults and geologic unconformities.

7. Conduct well pumping tests using existing and additional test wells as required. Previous information on geologic formations and groundwater conditions should be used to establish the locations and spacings of the test wells.

8. Measure and tabulate aquifer parameter values, such as conductivity, transmissivity, recharge, and discharge. Identify geologic and land use characteristics which can be used to specify these parameters on a zonal or spatial basis.

This field information would enable realistic predictions to be made of the impacts of coal mining activities on both the quantity and quality aspects of groundwater hydrology.

Law review

Current laws and regulations, designed to protect the environment, may prevent management techniques that could produce hydrologic benefits. For example, water that might otherwise be available for beneficial use would be lost to evaporation if the law necessitates the total containment of discharged minewater. An examination of current laws applicable to the coal mining industry is necessary to determine if the best interests of both humankind and the environment are being served.

Development of projects

Non-appropriated minewater discharge should be developed for local agricultural, municipal, and industrial uses. Such projects would necessitate cooperation and cost-sharing between the coal industry and local communities or other user groups. A demonstration project may be needed to convince the public that coal mines represent a potential source of water and that the coal mining industry is a potential benefactor to the environment.

LITERATURE CITED

Adams, T. C. 1934. Evaporation from Great Salt Lake. American Meteorological Society, Bulletin, 15(1):35-39.

Agnew, Allen F. 1971. Coal mining hydrology and the environment, or give the devil his due. Preprint Paper No. EQC 37, American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, N.Y.

Aldon, Earl F., and H. W. Springfield. 1978. Reclaiming coal mine spoils in the four corners. In: Reclamation and use of disturbed land in the southwest. John L. Thames, editor. University of Arizona Press, Tucson, Arizona.

Brauer, Courtney. 1977. Wastewater quality management 208 plan for Carbon, Emery, and Grand County. (under review)

Brauner, Gerhard. 1973. Subsidence due to underground mining. U.S. Department of the Interior, Bureau of Mines Information Circular 8571 and 8572.

Civil Engineering. 1977a. Can the U.S. cope with skyrocketing coal production? 47(1):43-45. January.

Civil Engineering. 1977b. How the Carter administration plans to cope with the energy crisis. 47(7):51-54. July.

Collier, Charles R., et al. 1964. Influences of strip mining on the hydrologic environment of parts of Beaver Creek Basin, 1955 - 1959. U.S. Geological Survey Prof. Paper 427-B, C.

Colorado River Basin Salinity Control Forum. 1977. Policy for implementation of the Colorado River salinity standards through the NPDES permit program.

Colorado River Basin Salinity Control Forum. 1978. Revision of water quality standards for salinity including numerical criteria and plan of implementation for salinity control of the Colorado River system.

Consolidation Coal Company. 1978. Emery mine mining and reclamation plan. U-52E7, January 25. Under review.

Cooley, R. L. 1979. A method of estimating parameters and assessing reliability for models of steady state groundwater flow. 2. Application of statistical analysis. Water Resources Research, 15(3):603-617.

Corbett, Don. 1976. Mined land has water storage and conservation potential, says expert. Mining Engineering, January.

Corbett, Don. 1978. Save water--turn to surface mining of coal. Water and Wastes Engineering. pp. 84-88. May.

Cordova, Robert M. 1964. Hydrogeologic reconnaissance of part of the headwaters area of the Price River, Utah. Utah Geological and Mineralogical Survey Water Resources Bulletin No. 4.

Danielson, T. W., and J. W. Hood. 1979. (Report in progress) Recharge to the Navajo sandstone in the lower Dirty Devil Basin, Utah. Probable publication as Water Resources Investigations Report of U.S. Geological Survey.

Division of Coal Production Technology. 1979. Western coal development monitoring system. A survey of coal mining capacity in the west. Office of Coal Supply Development, Resource Applications, Department of Energy, Washington, D.C.

Doelling, H. H. 1972. Utah coal fields monograph series 1-3. Utah Geological and Mineralogical Survey, Salt Lake City, Utah.

Dunrud, Richard. 1976. Some engineering geologic factors controlling coal mine subsidence in Utah and Colorado. U.S. Geological Survey Professional Paper 969. U.S. Government Printing Office, Washington, D.C.

Federal Register. 1979. Part II. Surface coal mining and reclamation operations permanent regulatory program. Book 3 of 3 books. March 13.

Feltis, R. D. 1966. Water from bedrock in the Colorado Plateau of Utah. Utah State Engineer Technical Publication No. 15. State Engineer's Office, Salt Lake City, Utah.

Freeze, R. A. 1975. A stochastic-conceptual analysis of one-dimensional groundwater flow in nonuniform homogeneous media. Water Resources Research, 11(5):725-741.

Gutjahr, A. L., L. W. Gelhar, A. A. Bakr, and J. R. MacMillan. 1978. Stochastic analysis of spatial variability in subsurface flows. 2. Evaluation and application. Water Resources Research, 14(5):953-959.

Hamilton, Bruce. 1977. Cleaning up the coal industry. Civil Engineering, 47(7):54-56. July.

Hansen, Roger D., Herbert A. Fullerton, A. Bruce Bishop, and Trevor C. Hughes. 1979. Historic and projected municipal and industrial water usage in Utah, 1960-1976. Utah Water Research Laboratory Report UWRL/P-79-02.

Hanshaw, Bruce B., and Gilman A. Hill. 1969. Geochemistry and hydrodynamics of the Paradox Basin Region, Utah, Colorado and New Mexico. Elsevier Publications, Amsterdam, Netherlands.

Herring, William C. 1978. Unpublished paper. Groundwater re-establishment in cast over burden.

Hood, J. W., and T. W. Danielson. 1979. (Report in progress). Bedrock aquifers in the lower Dirty Devil River Basin, Utah, with special emphasis on the Navajo sandstone. Probable publication as U.S. Geological Survey Open File Report.

Intermountain Consultants and Planners. 1977a. Possible effects of coal mining on the hydrologic regime of the south end of east mountain in south-central Utah. A report prepared for Utah Power and Light Company.

Intermountain Consultants and Planners. 1977b. Monitoring the hydrologic regime of the south end of east mountain in south-central Utah. A report prepared for Utah Power and Light Company.

Israelsen, C. Earl, and Frank W. Haws. 1978. Groundwater and surface water investigation report. Utah Water Research Laboratory, Logan, Utah.

Jeppson, Roland W., Gaylen L. Ashcroft, A. Leon Huber, Gaylord V. Skogerboe and Jay M. Bagley. 1968. Hydrologic atlas of Utah. Utah Water Research Laboratory, Utah Agricultural Experiment Station, Utah State University. November.

Jones, Douglas K. 1933. A study of the evaporation of the water of Great Salt Lake. M.S. Thesis, University of Utah Department of Civil Engineering.

Jones, Craig T., Calvin G. Clyde, William J. Grenney, and J. Paul Riley. 1976. Development of a water quality model applicable to Great Salt Lake, Utah. Utah Water Research Laboratory PRJEW 026-1, Utah State University, Logan, Utah.

Linsley, Ray K., and Joseph B. Franzini. 1972. Water-resources engineering. McGraw-Hill Book Company, New York, N.Y.

National Academy of Sciences. 1974. Rehabilitation potential of western coal lands. Ballinger Publishing Company, Cambridge, Massachusetts.

Nielson, George. 1978. Keystone forecasts 765 million tons of new coal capacity by 1987. Coal Age, pp. 113-114. February.

Nielson, George. 1979. Keystone predicts rapid expansion. Coal Age, 84(2):110. February.

Office of Legislative Research. 1976. Utah energy report no. 8, December. Report to Joint Legislative Committee on Energy Policy.

Osterwald, Frank W., and John O. Maberry. 1974. Engineering geologic map of the Woodside Quadrangle, Emery and Carbon counties, Utah. U.S. Geological Survey Miscellaneous Investigations Series Map 1-798. U.S. Geological Survey, Washington, D.C.

Pacific Southwest Inter-Agency Committee Report of the Water Management Subcommittee. 1968. Factors affecting sediment yield and measures for the reduction of erosion and sediment yield. October.

Personal communication with Earl Israelsen, research engineer at Utah Water Research Laboratory. July 10, 1979.

Personal communication with Bryce Montgomery, Utah Division of Water Resources. June 27, 1979.

Price, Don, and Ted Arnow. 1974. Summary and appraisals of the nation's groundwater resources--Upper Colorado River Basin. U.S. Geological Survey Professional Paper 813-C, U.S. Government Printing Office, Washington, D.C.

Price, Don, and Louise L. Miller. 1975. Hydrologic reconnaissance of the southern Uinta Basin, Utah and Colorado. State of Utah Department of Natural Resources Technical Publication No. 49.

Public Law 92-500. 1972. Amendments to federal water pollution control act. United States Statutes at Large, Vol. 86. U.S. Government Printing Office, Washington, D.C.

Riley, J. Paul, David S. Bowles, and Eugene K. Israelsen. 1978. Management of the hydrologic system in areas subject to coal mining activities. Research proposal submitted through Utah Center for Water Resources Research to Office of Water Research and Technology, Utah State University, Logan, Utah.

Shepard, John W. 1973. Utah coal. Coal Age, pp. 159-177. April.

Shih, Sun-Fu. 1973. Modified Monte Carlo application to groundwater movement--the simultaneity procedures. Water Resources Research, 9(4):1029-1038.

Shoemaker, Jay. 1962. Fine coal recovery and mine backfill preparation. Mechanization. October. pp. 30-34.

Shown, L. M. 1970. Evaluation of a method for estimating sediment yield. U.S. Geological Survey Professional Paper 700-B. U.S. Government Printing Office, Washington, D.C.

Skelly and Loy, Consulting Engineers. The utilization of coal mine and mine mouth conversion plant waste waters for fish and wildlife habitat enhancement. U.S. Fish and Wildlife Service Contract No. 14-16-0009-77-042.

Spieker, Edmund M. 1931. The Wasatch Plateau coal field, Utah. U.S. Geological Survey Bulletin 819. U.S. Government Printing Office, Washington, D.C.

Udall, Stewart L. 1967. Surface mining and our environment. A special report to the nation. U.S. Department of the Interior. U.S. Government Printing Office, Washington, D.C.

U.S. Bureau of Land Management. 1975. Resource and potential reclamation evaluation Alton study site Alton coal field. EMRIA report no. 4. Salt Lake City, Utah.

U.S. Bureau of Land Management. 1978a. Rehabilitation potential for the Henry Mountain coal field. EMRIA Report No. 15. Salt Lake City, Utah.

U.S. Bureau of Land Management. 1978b. The effects of surface disturbance. (Primarily livestock use) on the salinity of public lands in the Upper Colorado River Basin (1977 status report). Denver Service Center, Div. of Standards and Technology Watershed Staff Colorado River Salinity Team.

U.S. Bureau of Land Management. 1979. Draft environmental statement Emery power plant units 3 and 4. U.S. Government Printing Office, Washington, D.C.

U.S. Bureau of Mines. 1978. Minerals in the economy of Utah. Department of the Interior. State Mineral Profile SMP-43.

U.S. Department of the Interior. 1978. Minerals in the economy of Utah. Bureau of Mines. State Mineral Profile SMP-43.

U.S. Environmental Protection Agency. 1975. Inactive and abandoned underground mines: water pollution prevention and control. EPA 440/9-75-007, Washington, D.C.

U.S. Geological Survey. 1964-1974. Water resources data for Utah. Part 2: Water quality records.

U.S. Geological Survey. 1975. Water resources for Colorado Part 2: Water quality records.

U.S. Geological Survey. 1975-1976. Water resources data for Utah. Water years 1975-1976.

U.S. Geological Survey. 1977. Water resources data for Colorado water year 1975. Vol. 2. Colorado River Basin. May.

U.S. Geological Survey. 1978a. Water resources data for Colorado water year 1976, Vol. 2. Colorado River Basin. January.

U.S. Geological Survey. 1978b. Water resources data for Utah water year 1977.

U.S. Geological Survey. 1978c. Water resources data for Colorado water year 1977. Vol. 2. Colorado River Basin Above Dolores River. December.

U.S. Geological Survey. 1978d. Draft environmental statement regional analysis--part I. Development of coal resources in central Utah. U.S. Government Printing Office, Washington, D.C.

U.S. Geological Survey. 1978e. Draft environmental statement site specific analysis--part II. Development of local resources in central Utah. U.S. Government Printing Office, Washington, D.C.

U.S. Geological Survey. 1978f. Draft environmental statement regional analysis--part I. Development of coal resources in southern Utah. U.S. Government Printing Office, Washington, D.C.

U.S. Geological Survey. 1978g. Draft environmental statement site-specific analysis--Part II. Development of coal resources in southern Utah. U.S. Government Printing Office, Washington, D.C.

U.S. Geological Survey. 1979. Unpublished data.

Upper Colorado Region State-Federal Inter-Agency Group. 1971. Upper Colorado region comprehensive framework study. Appendix VIII: Watershed management.

Utah Division of Health. 1977. Wastewater analyses. 1976 Tabulation. Department of Social Services, Salt Lake City, Utah.

Utah Division of Health. 1978. Unpublished water quality data.

Utah Division of Oil, Gas and Mining. 1979. Personal communication.

Utah Water Research Laboratory. 1975. Colorado River regional assessment study. Part 1: Executive summary basin profile and report digest. Utah State University, Logan, Utah.

Waddell, K. M., H. L. Vickers, Robbin T. Upton, and P. Kay Contratto. Selected hydrologic data, 1931-77, Wasatch Plateau-Book Cliffs coal fields area, Utah. U.S. Geological Survey Open-File Report 78-121. Salt Lake City, Utah.

Yakowitz, S. 1976. Model-free statistical methods for water table prediction. Water Resources Research, 12(5):836-844.

APPENDIX A

TITLE LOCATIONS--OF MAJOR COAL MINES IN UTAH

Table A.1. Coal mines in Utah (from Utah Division of Oil, Gas and Mining).

	Mine Name	Type	Location	Status
		BOOK CLIFFS COAL FIELD (see Figure A.1)		
1.	Braztah Complex	Underground	T. 12, 13S., R. 8-10E.	Producing
2.	Entech	Underground	Sec. 26, T. 13S., R. 9E.	Not producing
3.	Zions Fee Mine	Underground	Sec. 7, T. 13S., R. 11E.	Not producing
4.	Soldier Canyon Mine	Underground	Sec. 18, T. 13S., R. 12E.	Producing
5.	Sage Point, Dugout Creek	Underground	T. 12-15S., R. 12&13E.	Not producing
6.	Sunnyside Complex	Underground	Sec. 19, T. 14S., R. 14E.	Producing
7.	Geneva Complex	Underground	Sec.'s 2,3,4,9,10,11,14,15,32,33, 34, T. 15S., R. 14E.	Producing
		WASATCH PLATEAU COAL FIELD (see Figure A.2)		
1.	Columbine #1	Underground	Sec. 33, T. 12S., R. 7E.	Not producing
2.	McKinnon #1 Mine	Underground	T. 13S., R. 6E.	Not producing
3.	McKinnon #3 Mine	Underground	Sec. 23, T. 13S., R. 6E.	Not producing
4.	McKinnon #2 Mine	Underground	Sec. 24, T. 13S., R. 6E.	Not producing
5.	Belina #1 & 2	Underground	Sec. 9&30, T. 13S., R. 7E.	Producing
6.	Utah #2 Mine	Underground	Sec. 8&17, T. 13S., R. 7E.	Not producing
7.	Gordon Creek #2	Underground	T. 13S., R. 7&8E.	Producing
8.	C and W #1 Mine	Underground	Sec.'s 7,8,16,17,18,20,21,8W T. 13S., R. 8E.	Not producing
9.	Gordon Creek #3 & 6	Underground	Sec. 16, T. 13S., R. 8E.	Producing
10.	Huntington #5 Mine	Underground	Sec. 25, T. 14S., R. 6E.	Producing
11.	Blazon #1 Mine	Underground	Sec. 4, T. 14S., R. 7E.	Not producing
12.	Hiawatha Complex	Underground	T. 15&16S., R. 7&8E.	Producing
13.	Star Point #1 & 2	Underground	T. 15S., R. 8E.	Producing
14.	Huntington #4 Mine	Underground	Sec. 16, T. 16S., R. 7E.	Producing
15.	Co-op Mine	Underground	Sec. 20, T. 16S., R. 7E.	Producing
16.	Bear Creek Canyon Mine	Underground	Sec. 25, T. 16S., R. 7E.	Not producing
17.	Trail Mountain Mine	Underground	Sec. 25, T. 17S., R. 6E.	Producing
18.	Deer Creek Mine	Underground	Sec. 10, T. 17S., R. 7E.	Producing
19.	Church Mines (Des, Bee, Dove)	Underground	Sec. 11,13,14,23,24,26, T. 17S., R. 7E.	Producing
20.	Wilberg Mine	Underground	Sec. 27, 34, T. 17S., R. 7E.	Producing
21.	Skutumpah Canyon Coal Mine	Underground	Sec. 12, T. 22S., R. 3E.	Not producing
22.	Convulsion Canyon Mine	Underground	Sec. 12, T. 22S., R. 4E.	Producing
23.	Rock Canyon Mine	Underground	Sec. 1, T. 23S., R. 3E.	Not producing
24.	Knight Mine	Underground	Sec. 34, T. 23S., R. 4E.	Producing
		EMERY COAL FIELD (see Figure A.3)		
1.	Emery Surface Mine	Surface	Sec.'s 22,28,33,34, T. 22S., R. 6E.	Not producing
2.	Emery Deep Mine	Underground	Sec.'s 28,29,33,32, T. 22S., R. 6E.	Producing
3.	Hidden Valley	Underground	Sec. 17&18, T. 23S., R. 6E.	Not producing
4.	Dog Valley Underground	Underground	Sec. 32, T. 23S., R. 6E.	Producing
5.	Dog Valley Surface	Surface	Sec. 32, T. 23S., R. 6E.	Not producing
6.	Ute #1 Mine	Underground	Sec.'s 5,6,7,8,17,18,19,20, T. 25S., R. 5E.	Not producing
7.	Ute #2 Mine	Underground	Sec.'s 13,19,23,24,25,26,30, T. 25S., R. 4E.	Not producing
		OTHER		
1.	Black Hawk Mine	Underground	Sec. 36, T. 3N., R. 6E.	Producing
2.	Buck Canyon Coal Mine	Surface	Sec. 36, T. 18S., R. 23E.	Not producing
3.	Thompson Coal Mine	Underground	Sec. 16, T. 20S., R. 20E.	Producing
4.	Black Ace Mine	Underground	Sec. 36, T. 20S., R. 20E.	Not producing
5.	Factory Butte	Surface	T. 27S., R. 9E.	Not producing
6.	Henry Mountain Coal Site	Underground	T. 31S., R. 8&9E.	Not producing
7.	Davies Mine	Underground	Sec. 36, T. 36S., R. 2W.	Not producing
8.	Shakespeare Mine	Surface	T. 36S., R. 2W.	Not producing
9.	George Frandson Mine	Underground	Sec. 12, T. 36S., R. 2E.	Not producing
10.	Old Kirker Mine	Underground	Sec. 29-32, T. 37S., R. 13W.	Not producing
11.	John Henry Mine	Underground	Sec. 2, T. 42S., R. 3E.	Not producing
12.	Blue Mine	Surface	Not available	Not producing

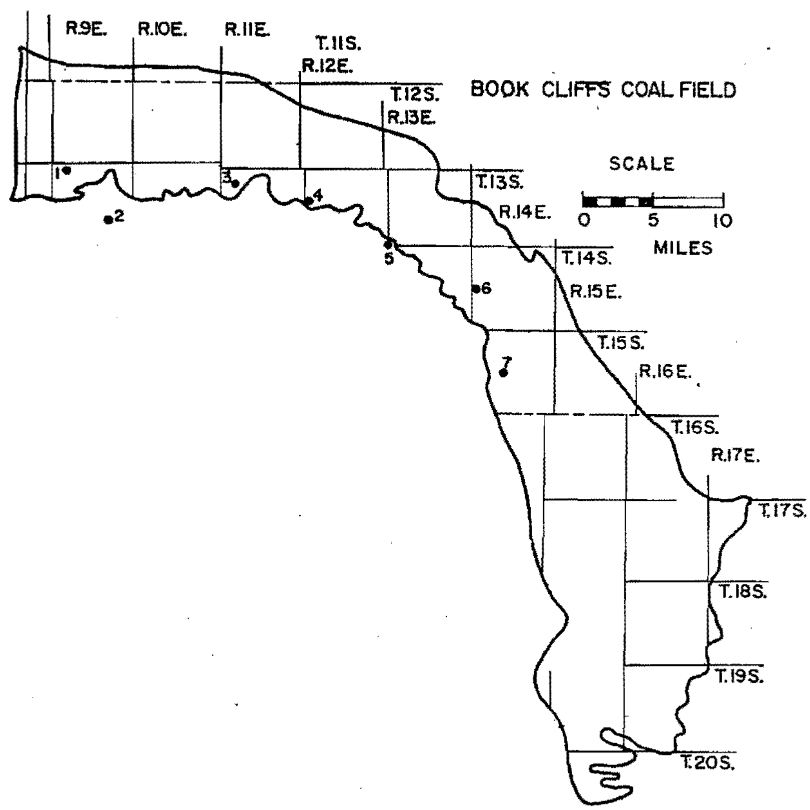


Figure A.1. Book Cliffs coal field. Mines 1-7 described in Table A.1 (base map from Doelling 1972, Vol. 3).

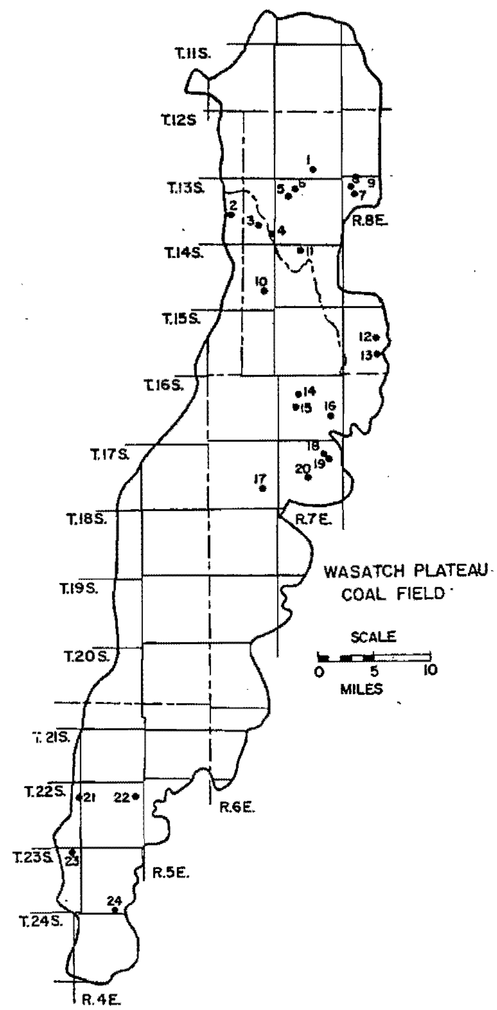


Figure A.2. Wasatch Plateau coal field. Mines 1-24 described in Table A.1 (base map from Doelling 1972, Vol. 3).

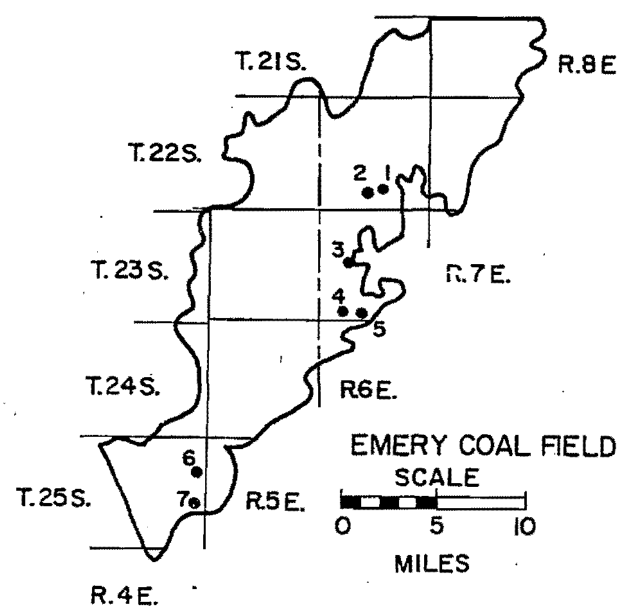


Figure A.3. Emery coal field. Mines 1-7 described in Table A.1 (base map from Doelling 1972, Vol. 3).

APPENDIX B

ESTIMATING SEEPAGE LOSSES FROM RETENTION PONDS--A PROGRAMMABLE CALCULATOR PROGRAM

The procedure used to estimate the seepage losses from retention ponds are described in Chapter VII of this report.

To assist in the solution of the equations for each step, a program has been written for the TI 59 Programmable Calculator. No print options have been used. If the program is modified, the steps between 107 and 133 must remain the same or the 'go to' statement at step 133 must be modified to reflect the new location of the current step 107. Otherwise there should be no problems in adding the desired print routines to the program. Several NOP spaces have been left for this purpose. No attempt has been made to abbreviate the program so that it will run on the TI 58 calculator. This can be done if the TI 58 is available rather than the TI 59. The storage locations will currently fit the TI 58 but the program would need to be revised. A combination of deleting memory requirements and program streamlining would make the program fit the smaller calculator. The first step would be to delete the initialization subroutine, A'.

The dimensions of the input data need to be outlined for correct operation of the program. The following list gives the input parameters and their corresponding dimensions:

	Parameter	Dimensions
1.	Initial storage, S_o	acre feet
2.	Inflow, I	acre feet
3.	Precipitation, PPT	inches
4.	Pan evaporation, E_{vp}	inches
5.	Suspended sediment concentration, $S\%_v$	% volume
6.	Suspended sediment coefficient of permeability	feet/month
7.	Pond bottom width, a	feet
8.	Pond bottom length, b	feet
9.	Pond embankment height, d	feet
10.	Pond embankment slope, s, @ 2:1 slope = 0.5	dimensionless
11.	Liner depth, L_l	feet
12.	Liner coefficient of permeability	feet/month
13.	Inflow salinity concentration, C_i	percent
14.	Storage salinity concentration, C	percent
15.	Settled sediment depth, L_s	feet
16.	Initial water depth in the pond, h_o	feet

The calculated parameters have corresponding units to the input parameters as shown in the following list:

	Parameter	Dimensions
16.	Final water depth, h_f	feet
17.	43560	square feet per acre or cubic feet per acre foot
18.	Pan to pond evaporation coefficient, m	dimensionless = 0.7
19.	Final pond storage, S_f	acre feet
20.	Calculated water depth, h_i	feet
21.	Pond evaporation, E_v	inches
22.	Average depth for evaporation, h_e	feet
23.	Average depth for seepage, h_s	feet
24.	Calculated storage, S	feet
25.	Total precipitation	acre feet
26.	Evaporation outflow, O_e	acre feet
27.	Seepage outflow, O_s	acre feet
29.	Sum of initial storage + inflow + precip	acre feet

No provision has been made in the program for limiting the final depth of water for any time period to the height of the embankment. The operator should look at the final depth at the end of each period to determine that the water does not overflow the pond banks. Other parameters can be watched as desired.

It is also apparent that the program can be used to design a total containment pond. If a run is made and the banks overflow, increase the dimensions of the pond bottom and rerun the inputs. Repeat the process until the pond has the safety factor desired. The subroutines could also be rearranged to make a more direct design tool.

The general operational instructions for the program are included in the program record sheets. The user defined keys, A through E, follow the outlined steps and solve the given equations. The user defined key, A', takes the final conditions from one time period and places them as the initial conditions for the next time period. The program is not hard to run and should give all of the necessary answers. Subroutines can be used alone for calculating parts of the parameters desired.

TITLE SEEPAGE FROM A TOTAL CONTAINMENT POND PAGE 1 OF 5

PROGRAMMER E.K.Israelsen DATE 1/26/1980

TI Programmable Program Record

Partitioning (Op 17) 4,7,9,5,9 Library Module ______ Printer ______ Cards 2

PROGRAM DESCRIPTION

Given the pond characteristics and the input measurements, the program calculates the seepage loss from the pond and updates the storage initial conditions for the next set of input data. The program was intended to use a monthly time increment for the input and storage data. Other calculations may be of interest and are available through the operation of the model. These parameters are listed in the memory storage section.

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS		DISPLAY
1	Enter the pond characteristics and the input data. Memories 1-15				
2	Calculate initial storage + inflows			A	
3	Iterate to determine h for that storage			B	
4	Subtract evaporation from h and average with initial h			C	
5	Calculate seepage and evaporation outflows and subtract from calculation of inflow + storage for estimate of the final storage.			D	
6	Calculate new depth for the estimated final storage. Compare the new final storage with the initial final storage calculation and, if different, use the new value as the initial estimate and recalculate h. Repeat the procedure until the new and previous values are within one acre foot of being the same.			E	
7	Recall the final value of the seepage outflow		RCL	27	Seepage outflow
8	Recall other parameters of interest by recalling the appropriate memory storage location, see list.		RCL	--	
9	Initialize the initial conditions for next period			A'	

USER DEFINED KEYS	DATA REGISTERS (INV List)		LABELS (Op 08)
A Equation 1	0 Initial storage	10 Bank slope	tan X
B Equation 2	1 Inflow	11 Liner depth	|x| X
C Equation 3 & 4	2 Precipitation	12 Liner k_s	Deg X
D Equations 4 & 5	3 Pan evaporation	13 Inflow concen. %	Rad X
E Test & repeat Calc.	4 Storage concentra	14 Sediment depth	Dsz X
A' Initialize next run	5 Susp.Sediment %	15 Initial H_2O depth	
B'	6 ~~Sediment k_s~~	~~16~~ Final " "	
C'	7 Pond base length	17 43560	
D'	8 Pond base width	18 0.7	
E'	9 Bank height	19 Final storage	

FLAGS 0 1 2 3 4 5 6 7 8 9

 1014986-1

TITLE SEEPAGE FROM A TOTAL CONTAINMENT POND PAGE 2 OF 5

PROGRAMMER Eugene K. Israelsen DATE 1/26/1980

TI Programmable Program Record

Partitioning (Op 17) Library Module Printer Cards

PROGRAM DESCRIPTION

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS	DISPLAY

USER DEFINED KEYS	DATA REGISTERS (INV List)	
A	20 Calculated h	0
B	21 Pond evaporation	1
C	22 Evap. avg. depth	2
D	23 Seepage avg. depth	3
E	24 Calculated storage	4
A'	25 Precip. ac-ft	5
B'	26 Evap. outflow ac-ft	6
C'	27 Seepage outflow ac-ft	7
D'	Storage for comparison	8
E'	29 Inflow + storage	9

LABELS (Op 08)

FLAGS 0 1 2 3 4 5 6 7 8 9

1014966-1

TITLE SEEPAGE FROM A TOTAL CONTAINMENT POND PAGE 3 OF 5

TI Programmable Coding Form

PROGRAMMER Eugene K. Israelsen DATE 1/26/1980

LOC	CODE	KEY	COMMENTS
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003	53	(	
004	43	RCL	
005	20	20	
006	33	X²	
007	65	×	
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010	43	RCL	
011	10	10	
012	33	X²	
013	85	+	
014	53	(	
015	43	RCL	
016	08	08	
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018	43	RCL	
019	07	07	
020	54	)	
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022	43	RCL	
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025	43	RCL	
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037	54	)	
038	68	NOP	
039	92	RTN	
040	68	NOP	
041	68	NOP	
042	68	NOP	
043	99	PRT	
044	76	LBL	
045	70	RAD	
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067	10	10	
068	85	+	
069	43	RCL	
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072	55	÷	
073	43	RCL	
074	17	17	
075	54	)	
076	22	INV	
077	71	SBR	
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080	53	(	
081	43	RCL	
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084	53	(	
085	01	1	
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091	43	RCL	
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094	65	×	
095	43	RCL	
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097	55	÷	
098	01	1	
099	02	2	
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102	68	NOP	
103	68	NOP	
104	68	NOP	
105	76	LBL	
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107	53	(	
108	43	RCL	
109	20	20	

LOC	CODE	KEY	COMMENTS
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113	54	)	
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116	59	INT	
117	32	X:T	
118	43	RCL	
119	19	19	
120	59	INT	
121	67	EQ	
122	30	TAN	
123	53	(	
124	43	RCL	
125	19	19	
126	55	÷	
127	43	RCL	
128	24	24	
129	68	NOP	
130	54	)	
131	49	PRD	
132	20	20	
133	61	GTO	
134	01	01	
135	07	07	
136	76	LBL	
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138	92	RTN	
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142	76	LBL	
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144	43	RCL	
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146	42	STO	
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MERGED CODES

62 Pgm Ind	72 STO Ind	83 GTO Ind
63 Exc Ind	73 RCL Ind	84 Op Ind
64 Prd Ind	74 SUM Ind	92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TITLE SEEPAGE FROM A TOTAL CONTAINMENT POND PAGE 4 OF 5

PROGRAMMER Eugene K. Israelsen DATE 1/26/1980

TI Programmable Coding Form

LOC	CODE	KEY	COMMENTS
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162	70	RAD	
163	54	)	
164	42	STO	
165	25	25	
166	95	=	
167	42	STO	
168	19	19	
169	42	STO	
170	29	29	
171	42	STO	
172	28	28	
173	91	R/S	
174	76	LBL	
175	12	B	
176	53	(	
177	43	RCL	
178	19	19	
179	55	÷	
180	43	RCL	
181	07	07	
182	55	÷	
183	43	RCL	
184	08	08	
185	65	×	
186	43	RCL	
187	17	17	
188	54	)	
189	42	STO	
190	20	20	
191	68	NOP	
192	71	SBR	
193	50	I×I	
194	43	RCL	
195	20	20	
196	92	RTN	
197	91	R/S	
198	76	LBL	
199	13	C	
200	43	RCL	
201	20	20	
202	75	-	
203	71	SBR	
204	80	GRD	
205	95	=	
206	42	STO	
207	16	16	
208	85	+	
209	43	RCL	
210	15	15	
211	95	=	
212	55	÷	
213	02	2	
214	95	=	

LOC	CODE	KEY	COMMENTS
215	42	STO	
216	22	22	
217	42	STO	
218	23	23	
219	91	R/S	
220	76	LBL	
221	14	D	
222	53	(	
223	71	SBR	
224	70	RAD	
225	65	×	
226	71	SBR	
227	80	GRD	
228	54	)	
229	42	STO	
230	26	26	
231	43	RCL	
232	23	23	
233	42	STO	
234	20	20	
235	53	(	
236	71	SBR	
237	60	DEG	
238	65	×	
239	43	RCL	
240	23	23	
241	55	÷	
242	53	(	
243	43	RCL	
244	11	11	
245	55	÷	
246	43	RCL	
247	12	12	
248	85	+	
249	43	RCL	
250	14	14	
251	55	÷	
252	43	RCL	
253	06	06	
254	54	)	
255	54	)	
256	42	STO	
257	27	27	
258	53	(	
259	43	RCL	
260	29	29	
261	75	-	
262	43	RCL	
263	26	26	
264	75	-	
265	43	RCL	
266	27	27	
267	54	)	
268	42	STO	
269	19	19	

LOC	CODE	KEY	COMMENTS
270	68	NOP	
271	68	NOP	
272	92	RTN	
273	91	R/S	
274	76	LBL	
275	15	E	
276	71	SBR	
277	12	B	
278	85	+	
279	43	RCL	
280	15	15	
281	95	=	
282	55	÷	
283	02	2	
284	95	=	
285	42	STO	
286	22	22	
287	42	STO	
288	23	23	
289	71	SBR	
290	14	D	
291	59	INT	
292	32	X⇌T	
293	43	RCL	
294	28	28	
295	59	INT	
296	67	EQ	
297	91	R/S	
298	43	RCL	
299	19	19	
300	42	STO	
301	28	28	
302	66	PAU	
303	66	PAU	
304	66	PAU	
305	15	E	
306	91	R/S	
307	91	R/S	
308	76	LBL	
309	16	A'	
310	53	(	
311	43	RCL	
312	00	00	
313	65	×	
314	43	RCL	
315	04	04	
316	85	+	
317	43	RCL	
318	01	01	
319	65	×	

MERGED CODES

62 Pgm Ind	72 STO Ind	83 GTO Ind
63 Exc Ind	73 RCL Ind	84 Op Ind
64 Prd Ind	74 SUM Ind	92 INV SBR

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TITLE SEEPAGE FROM A TOTAL CONTAINMENT POND PAGE 5 OF 5

PROGRAMMER Eugene K. Israelsen DATE 1/26/1980

TI Programmable Coding Form

LOC	CODE	KEY	COMMENTS
320	43	RCL	
321	13	13	
322	75	-	
323	43	RCL	
324	27	27	
325	65	×	
326	43	RCL	
327	04	04	
328	54	)	
329	55	÷	
330	43	RCL	
331	19	19	
332	42	STO	
333	00	00	
334	95	=	
335	68	NOP	
336	42	STO	
337	04	04	
338	43	RCL	
339	01	01	
340	65	×	
341	43	RCL	
342	05	05	
343	55	÷	
344	01	1	
345	00	0	
346	00	0	
347	55	÷	
348	53	(	
349	43	RCL	
350	16	16	
351	42	STO	
352	15	15	
353	42	STO	
354	22	22	
355	71	SBR	
356	70	RAD	
357	54	)	
358	95	=	
359	44	SUM	
360	14	14	
361	91	R/S	

MERGED CODES

62 Pgm Ind, 63 Exc Ind, 64 Prd Ind, 72 STO Ind, 73 RCL Ind, 74 SUM Ind, 83 GTO Ind, 84 Op Ind, 92 INV SBR

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APPENDIX C

USE OF STOCHASTIC METHODS IN GROUNDWATER FLOW ANALYSIS

When evaluating the properties of aquifers from pumping tests it is not widely appreciated that flow through non-uniform or heterogeneous porous media is basically stochastic in nature. Parameters are assumed to be constant in the formulation of deterministic flow models. The realistic assessment of groundwater flows in and around Utah coal fields, spatial differences in parameter estimates need to be considered.

In the stochastic approach, hydrogeologic parameters, such as hydraulic conductivity, soil compressibility, and porosity, are represented by probability distributions. Hydraulic conductivity, for example, can be approximated by a log normal distribution. If the aquifer properties do not depend on the orientation of a porous medium, the medium is said to be isotrophic. This is a common assumption for groundwater studies. In this chapter some of the possible approaches to stochastic groundwater flow analysis are outlined.

Monte Carlo Methods

The effects of random distributions in various soil and aquifer properties and in their measurement can be studied through Monte Carlo simulation methods. These properties include parameters such as initial and boundary heads, rate of pumping, aquifer thickness, hydraulic conductivity, and storage coefficient.

Monte Carlo simulation in groundwater hydrology may refer to a set of repetitive solutions with a mathematical model and the associated statistical analysis of the results. In a study by Freeze (1975), for any spatial distribution of hydraulic conductivity which is log normally generated, the hydraulic head, ϕ, is calculated for one-dimensional, steady-state, saturated flow in the x direction through a porous medium, using the fundamental equation

$$\frac{\partial}{\partial} K(x) \frac{\partial \phi}{\partial x} = 0,$$

where $K(x)$ is the hydraulic conductivity at any point, x. In this way the probability distributions of other properties such as porosity and compressibility also can be studied.

Alternatively, it is possible to use random walk methods of solving specific boundary value problems. Here, steps taken by flow particles in a medium represent a random walk between two boundaries. When a particle hits a boundary, its motion may be terminated or it may be reflected back; the path it takes depends on the boundary condition. On the negative side, computer time can be excessive in such studies. The simultaneity procedure of Shih (1973) is said to reduce this by some 30 to 60 percent. The basic idea is that without investigating the "ad hoc" motion of a single particle from point to point in a zone, one studies the simultaneous movement of n particles at the same probability for a set of n points. In summary, the scope for tackling these and other problems through Monte Carlo seems to be unlimited.

Analytical Approaches to the Problems of Three Dimensional Flow

The variation of hydraulic conductivity in aquifer soils is very complex indeed. This property has in fact the largest influence on flow. Realistically, one may think of it as a stochastic process in space having a characteristic covariance function. This is lacking in the Freeze (1975) model which is also confined to the one-dimensional case and does not give an overall measure of performance; likewise, ordinary Monte Carlo random walk models ignore spatial correlation effects. Covariance functions have been used in other spatial studies involving random variables, for example, in atmospheric turbulence. In a homogeneous case of groundwater flow, the discharge vector q can be represented by:

$$q = -\underline{K} \nabla\phi$$

where $\underline{K}$ is the matrix of hydraulic conductivity. Gutjahr et al. (1978) used spectral analysis (which can be applied to any number of dimensions) to solve the stochastic differential equation which describes flow through porous media with randomly varying hydraulic conductivity. Homogeneity in this sense means that the record of each well in a region is a different realization of the same process; that is, one expects to find that the variability of the log hydraulic conductivity or any other property is constant throughout the total thickness of a geologic formation. More precisely, statistical homogeneity can be expressed by using the auto-covariance function.

$$R_f(\xi, x) = E[f(x + \xi)f(x)]$$

Here the specific property represented by f is homogeneous if the auto-covariance depends on the spacing $\xi = x_1 - x_2$ and not on the location x in the geological unit. These assumptions together with the more restrictive one of statistical isotrophy (ignoring the question of time invariance) could, however, limit the practical use of such models.

Time Series and Regression Procedures

Time series procedures, linear and nonlinear methods of regression, clustering and associated techniques offer better scope for circumventing some of the assumptions such as that of statistical homogeneity. Water level depths may be viewed as random sequences and statistical laws established for each subregion. Using time series and clustering methods Yakowitz (1976) forecast depths in wells in the Tucson Basin of Arizona and found an encouraging measure of success when comparisons were made with observed values. The main drawback is that the amount of data available even in an intensely studied area may not be sufficient to validate anything more than a basic model. Consequently standard errors may be large and there is the additional problem of model choice.

Estimates of parameters in a groundwater model and the reliabilities of model predictions are affected by errors in observed data. Methods of statistical regression can be advantageously used to estimate the effect of such errors. In a case study of Truckee Meadows in the western semiarid part of Nevada, Cooley (1979) applied regression techniques to estimate parameters such as conductivity. The set of optimal parameters was chosen so that the objective function

$$S = e^T \underset{\sim}{\omega} e$$

was minimized. Here e is a residual vector of differences between observed and predicted heads, T denotes transpose and $\underset{\sim}{\omega}$ is a diagonal weight matrix. However, solutions were found to be non-unique. On the other hand, a close examination of the residuals, which should be an essential part of any regression analysis, should lead to more dependable predictions.

Summary

Although statistical, probabilistic and time series models may have inherent deficiencies, judicious application of one or more methods could help to resolve some of the uncertainties inherent in groundwater flow analysis. At the very least they provide a means of assessing errors in deterministic models which ignore the variability in parameters. Nevertheless, for meaningful results to be obtained, data bases need to be extended and the necessary field work ought to be undertaken for this purpose. These requirements are itemized in the "Recommendations" section of Chapter VIII.