POTENTIAL EFFECTS OF ANTICIPATED COAL MINING ON SALINITY OF THE PRICE, SAN RAFAEL, AND GREEN RIVERS, UTAH

by K. L. Lindskov

U.S. Geological Survey

Water-Resources Investigations Report 86-4019

Prepared in cooperation with the
U.S. DEPARTMENT OF THE INTERIOR
OFFICE OF SURFACE MINING
RECLAMATION AND ENFORCEMENT

Salt Lake City, Utah

1986

UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
Water Resources Division
1016 Administration Building
1745 West 1700 South
Salt Lake City, Utah 84104

Copies of this report can be
purchased from:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25425, Federal Center
Denver, Colorado 80225
(Telephone: (303) 236-7476)

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

For use of readers who prefer to use metric units, conversion factors for inch-pound units used in this report are listed below:

Multiply	By	To obtain
Acre-foot	1,233	Cubic meter
Cubic foot per second	0.02832	Cubic meter per second
Foot	0.3048	Meter
Inch	25.40	Millimeter
Mile	1.609	Kilometer
Square mile	2.590	Square kilometer
Ton	0.9072	Metric ton

Air temperature is given in degrees Fahrenheit (°F), which can be converted to degrees Celsius (°C) by the following equation:

$$^{\circ}C = (^{\circ}F - 32)/1.8.$$

POTENTIAL EFFECTS OF ANTICIPATED COAL MINING ON SALINITY OF THE PRICE, SAN RAFAEL, AND GREEN RIVERS, UTAH

By K. L. Lindskov

ABSTRACT

The impact of anticipated coal mining in Utah on the salinity of the Price, San Rafael, and Green Rivers is to be addressed in the repermitting of existing mines and permitting of new mines. To determine the potential impacts, mathematical models were developed for the Price and San Rafael River basins. It was assumed that the maximum quantity of ground water discharged from each mine would occur simultaneously for all mines; thus, a worst-case condition is presented. Little impact on the quantity and quality of streamflow is expected for the Price and San Rafael Rivers.

The increase in mean monthly flow of the Price River downstream from Scofield Reservoir is projected as 3.5 cubic feet per second, ranging from 1.7 percent in June to 140 percent in February. The potential increase in dissolved-solids concentration downstream from Scofield Reservoir would range from 10.4 percent in June and July (from 202 to 223 milligrams per liter) to 97.0 percent in February (from 202 to 398 milligrams per liter). However, the concentration of the mixture of mine water with the existing flow released from Scofield Reservoir would contain less than 500 milligrams per liter of dissolved solids.

At the mouth of the Price River, the potential increase in mean monthly flow is projected as 12.6 cubic feet per second, ranging from 3.7 percent in May to 37.7 percent in January. The potential changes in dissolved-solids concentration would range from a 20.7 percent decrease in January (from 3,677 to 2,917 milligrams per liter) to a 1.3 percent increase in June (from 1,911 to 1,935 milligrams per liter).

At the mouth of the San Rafael River, the potential increase in mean monthly flow ranges from 2.9 cubic feet per second in February to 6.7 cubic feet per second in May, with the increase ranging from 0.8 percent in June to 12.6 percent in November. The potential changes in dissolved-solids concentration would range from a 5.3 percent decrease in March (from 2,318 to 2,195 milligrams per liter) to a 0.6 percent increase in May (from 1,649 to 1,659 milligrams per liter).

The anticipated mining in the Price and San Rafael River basins is not expected to cause a detectable change in the quantity and quality of streamflow in the Green River. The combined average flow of the Price and San Rafael Rivers is about 4 percent of the average flow in the Green River. The projected peak increase in flow resulting from discharge from the mines is less than 0.3 percent of the average flow in the Green River. The combined dissolved-solids load from the anticipated mining in the Price and San Rafael River basins represents less than 0.8 percent of the average annual dissolved-solids load of the Green River. Thus, it would be difficult to detect any change in dissolved-solids concentrations of the Green River.

INTRODUCTION

A hydrologic investigation of the Price, San Rafael, and Green Rivers was made by the U.S. Geological Survey during 1983-85 at the request of the Office of Surface Mining. The primary purpose of the investigation was to determine if salts resulting from anticipated coal mining in the Price and San Rafael River basins would cause a detectable increase in the salinity of the Green River, which is the largest tributary of the Colorado River. In addition, the investigation evaluated the possible impacts on the flow of the three rivers.

Concern for the salinity of the Colorado River and its tributaries has resulted in much legislation. The Colorado River Basin Water Quality Control Project was established in 1960 by a joint Federal-State conference to consider salinity problems. Detailed studies of such problems in the basin began in 1963 and are reported by Blackman and others (1973). In 1964, Public Law 93-320 authorized the construction of four salinity-control projects and the expedited completion of planning reports for 12 additional salinity-control units, including the Price and San Rafael River basins. The Federal Water Pollution Control Amendment (PL92-500) was passed in 1972, and the Environmental Protection Agency proposed an interstate organization to develop a salinity-control plan. The Colorado River Basin Salinity Control Forum was formed in 1973. This resulted in establishment of criteria for average flow-weighted dissolved-solids concentrations for the Colorado River below Hoover, Parker, and Imperial Dams, with respective values of 723, 747, and 879 milligrams per liter.

The average annual salt load for water years 1914-57 from the Upper Colorado River Basin measured at Lees Ferry, AZ, was about 8.6 million tons (U.S. Geological Survey, 1964, table 19). The Price and San Rafael River basins contributed about 242,000 and 190,000 tons, a significant part of the total load in the basin. Thus, it is important that the impact from coal mining in these basins be addressed in the repermitting of existing mines and permitting of new mines.

The overall objective of this report is to describe the potential cumulative impacts of anticipated coal mining on the dissolved-solids concentrations in the Price, San Rafael, and Green Rivers. The changes considered were (1) salt loads in ground water that would be intercepted by mines and discharged to nearby streams in order to dewater the mines and (2) salt loads resulting from surface disturbance associated with the anticipated mining. The anticipated salt loads were estimated from (1) reports prepared under contract with the Office of Surface Mining Reclamation and Enforcement--Cumulative Hydrologic Impact Assessments of several drainages tributary to the Price and San Rafael Rivers that may be impacted by the mining, (2) information from determinations of probable hydrologic impacts in individual permit applications submitted to the Utah Division of Oil, Gas, and Mining, (3) monitoring reports for the National Pollutant Discharge Elimination System furnished to the U.S. Environmental Protection Agency, and (4) other miscellaneous monitoring data for the permit areas.

Mathematical models developed by the U.S. Geological Survey for the Price and San Rafael River basins (fig. 1) route streamflow and dissolved-solids loads through a stream network by the use of an accounting procedure that sums quantity and quality of mean monthly flow in a downstream direction. The models were calibrated for existing conditions by comparing computed flow and dissolved-solids concentrations to values determined from gaging-station records. The projected ground-water discharge and salt load from ground water and from areas of surface disturbance were combined with the model results for existing conditions, and the quantity and quality of streamflow before and after mining were compared.

PHYSICAL, GEOLOGIC, AND HYDROLOGIC SETTING

Price River Basin

The Price River basin, which includes about 1,800 square miles in six counties, is mainly in Carbon and Emery Counties in east-central Utah. (See figure 1). The basin occupies parts of three physiographic sections of the Colorado Plateau--the Uinta Basin to the north, High Plateaus to the west, and Canyon Lands to the south and east (Fenneman, 1946). The Price River drainage originates in the Wasatch Plateau about 12 miles west and south of Scofield Reservoir; and downstream of the reservoir, the river flows in a generally southeasterly direction. The drainage is bounded by the Book Cliffs on the northeast, the Wasatch Plateau on the west, and the San Rafael Swell on the south. Altitudes range from greater than 10,000 feet in the headwaters to about 4,200 feet above sea level at the mouth where the Price River joins the Green River.

Rocks that crop out in the coal-producing areas of the basin consist mainly of sandstone, mudstone, and shale (fig. 2). The reader is referred to Hintze (1980) for a general geologic map of the area.

The Blackhawk Formation of Cretaceous age is the most important coal-producing unit in the basin. Coal is mined from the Blackhawk in the Wasatch Plateau and Book Cliffs with underground techniques, and all future mining probably will be with underground techniques. Except for some areas of the Book Cliffs where the Blackhawk intertongues with the Mancos Shale of Cretaceous age, the Blackhawk is underlain by the Star Point Sandstone of Cretaceous age. The Blackhawk in most coal-producing areas is overlain by about 2,000 feet of mainly sandstone and mudstone. The highest areas of the Wasatch Plateau are capped by cliff-forming limestone in the Flagstaff Limestone of Tertiary age, whereas in the Book Cliffs the highest areas usually are capped by the Colton Formation of Tertiary age.

Shales in the Mancos Shale that overlie the Ferron Sandstone Member generally crop out along the downstream reaches of streams tributary to the Price River. The Mancos is the predominant geologic influence on the chemical quality of water that enters the Price River downstream from Helper.

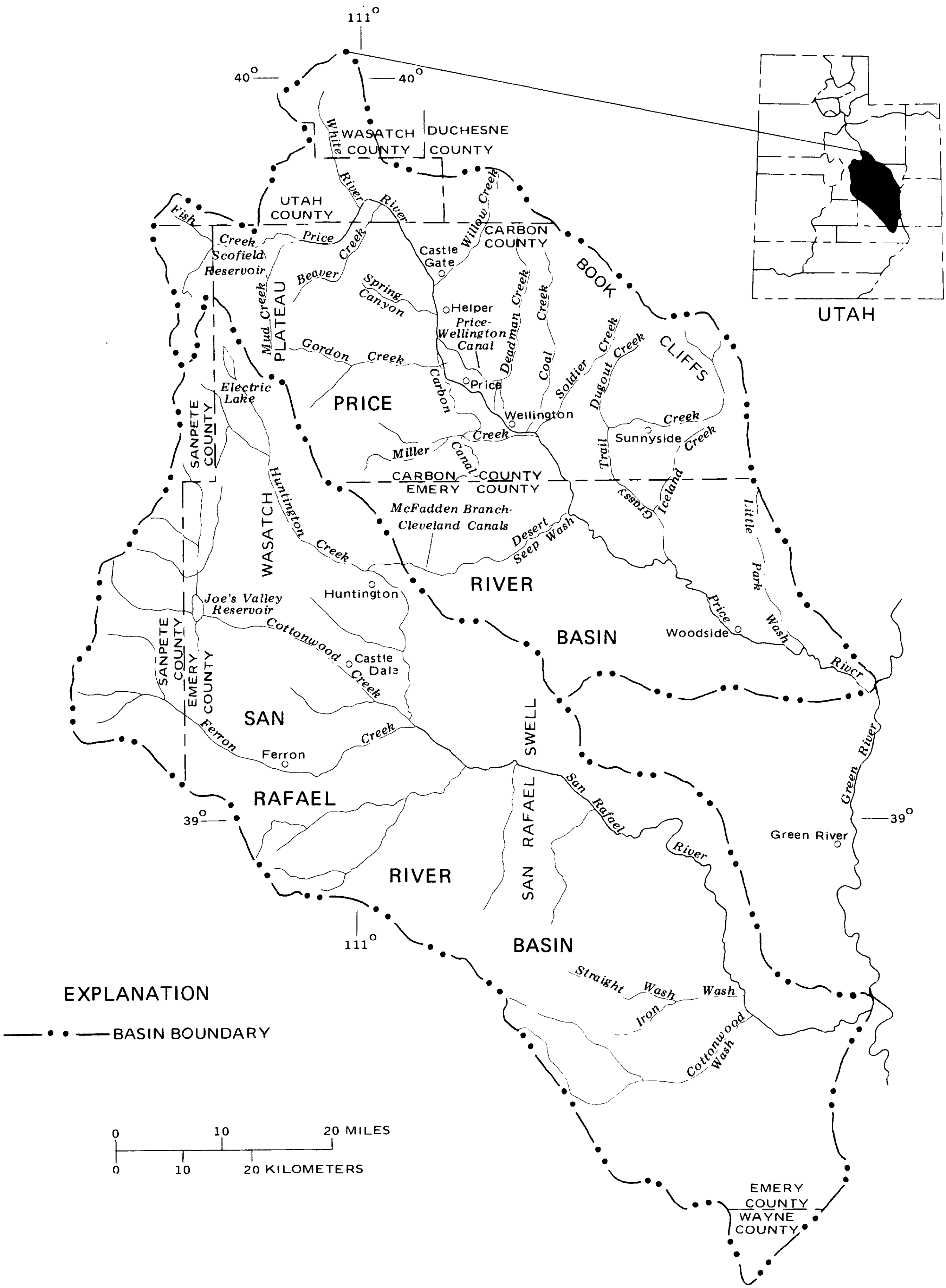

Figure 1.—Location of study area, with outlines of the Price and San Rafael River drainages.

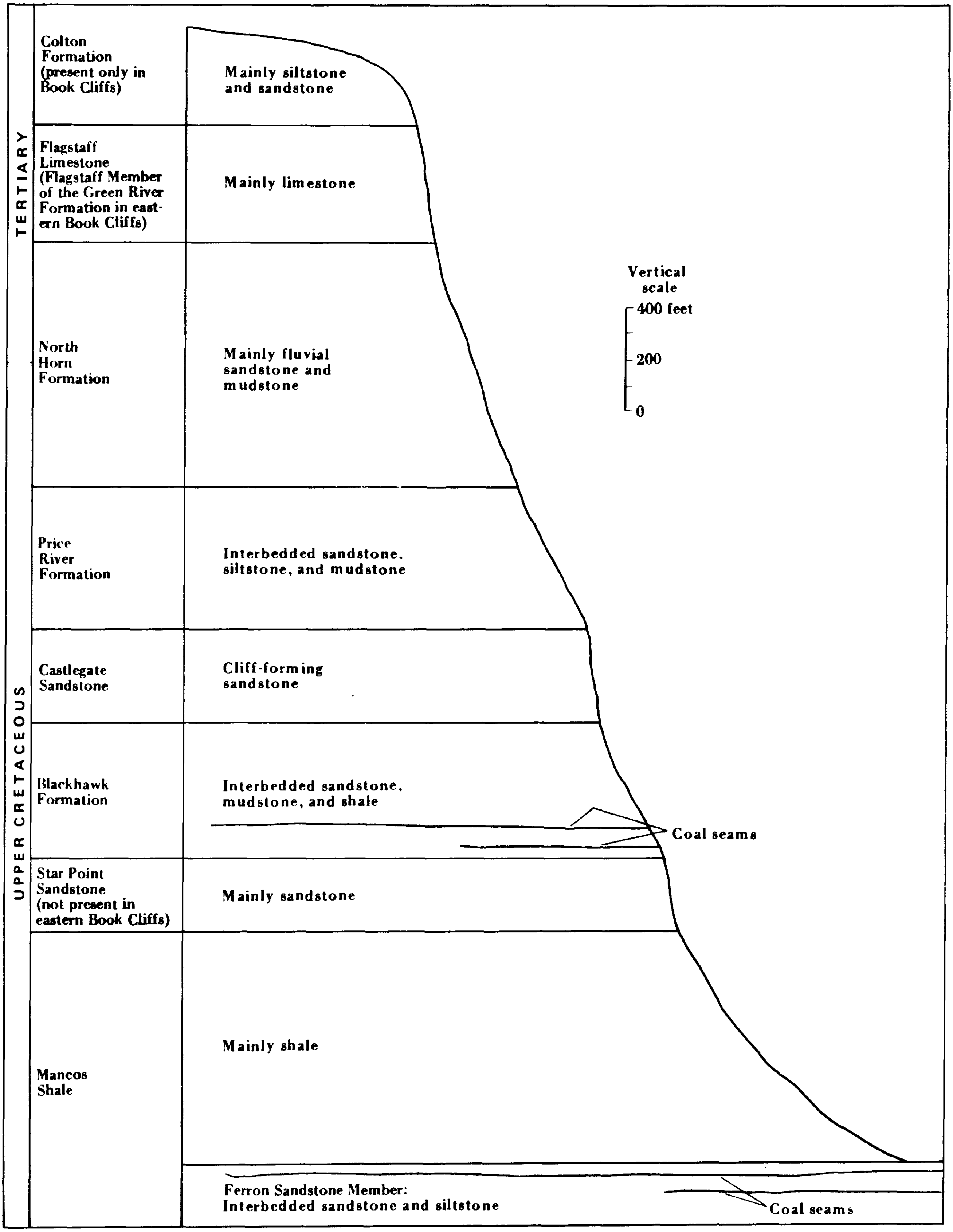

Figure 2.—Diagrammatic geologic column for the coal-fields area in the Price and San Rafael River basins (from Lines and Plantz, 1981, fig. 1).

The average annual precipitation in the Price River basin ranges from about 8 inches in the southern part to more than 30 inches in the extreme northwestern part (U.S. Weather Bureau, 1963). Above 8,000 feet, the climate is subhumid. Precipitation generally is less above 7,000 feet along the northeastern part of the basin than it is at similar altitudes in the western or headwaters part of the basin. On the average, about 50 percent of the total precipitation on the basin falls on the upstream 30 percent of the area. About 70 percent of the precipitation falls on areas with altitudes greater than 6,000 feet, and about 65 percent of this total falls as snow during October-April (Mundorff, 1972, p. 6). Most of the precipitation that falls on the lower altitudes comes from thunderstorms during the late summer months. The mean annual air temperature ranges from about 35 degrees Fahrenheit at the higher altitudes to about 50 degrees Fahrenheit at altitudes below 6,000 feet. The normal annual free-water surface evaporation is between 35 and 45 inches (Farnsworth and others, 1982, map 3).

The streamflow that originates in the Book Cliffs is small in comparison to that of streams that originate in the Wasatch Plateau, and the difference reflects differences in precipitation. The quality of streamflow generally deteriorates downstream because of return flow from irrigation on saline soils developed by weathering of the Mancos Shale. In the mountains, dissolved-solids concentrations generally range from about 100-600 milligrams per liter, whereas concentrations in the downstream reaches of streams that cross the Mancos often exceed 2,000 milligrams per liter.

Scofield Reservoir, which has a usable capacity of 65,780 acre-feet, regulates the flow of about the upstream 10 percent of the Price River basin. The White River and Willow Creek are major streams contributing flow to the Price River between Scofield Reservoir and the points of diversions to the Price-Wellington and Carbon Canals.

Water from most springs and mines in the Wasatch Plateau and Book Cliffs contains about 200-800 milligrams per liter of dissolved solids. Water from mines in the Book Cliffs in the northeastern part of the basin generally contains about 800 to 1,600 milligrams per liter of dissolved solids. The chemical quality of the ground water varies considerably within each formation, but not enough is known about the ground-water system to explain these variations. They are related, however, to differences in lithology, time in contact with water-bearing units, and the flow path between recharge and discharge areas (Lines and Plantz, 1981, p. 6).

San Rafael River Basin

The San Rafael River basin, which includes about 2,300 square miles in three counties, is mainly in Emery County to the south of the Price River basin. (See figure 1.) The basin occupies parts of two physiographic sections of the Colorado Plateau--the High Plateaus to the north and west and Canyon Lands to the south and east (Fenneman, 1946). Principal streams in the basin are Huntington and Cottonwood Creeks, which merge to form the San Rafael River, and Ferron Creek, which joins the San Rafael River within a mile downstream. Altitudes in the basin range from about 4,000 feet at the mouth of the San Rafael River to more than 11,000 feet in the headwaters of Cottonwood Creek. Altitudes in the headwaters of Huntington, Cottonwood, and Ferron Creeks commonly range from 9,000 to 11,000 feet.

Rocks that crop out in the upstream third of the basin are similar to those shown in figure 2. Some older rocks of Jurassic, Triassic, Permian, and Pennsylvanian age (Hintze, 1980, sheet 2) crop out in the downstream two thirds of the basin. The Carmel Formation of Jurassic age and various members of the Mancos Shale are major contributors of dissolved-solids load to streams in the basin. These rocks crop out extensively in the central part of the basin (Mundorff and Thompson, 1982, pl. 1).

All coal in the San Rafael River basin is mined from the Blackhawk Formation with underground techniques, and all future mining probably will be with underground techniques. Most coal mining is in the upstream drainages of Huntington and Cottonwood Creeks.

The average annual precipitation ranges from about 6 inches in the southeast or downstream part of the San Rafael River basin to 40 inches or more in the northwest in small headwater areas (U.S. Weather Bureau, 1963). Above 8,000 feet the climate is subhumid. A large part of the total precipitation on the basin falls over the upstream mountainous areas where 70 percent or more of the annual precipitation falls as snow during October-April. As in the Price River basin, most of the precipitation that falls on the lower altitudes comes from thunderstorms during late summer. The mean annual air temperature ranges from about 35 degrees Fahrenheit at the higher altitudes to about 55 degrees Fahrenheit near the mouth of the basin. The normal annual free-water surface evaporation is between 40 and 55 inches (Farnsworth and others, 1982, map 3).

Eight major reservoirs with a total usable capacity of 115,000 acre-feet regulate the flow of Huntington, Cottonwood, and Ferron Creeks. From April to October, major diversions downstream from the reservoirs nearly deplete the flow of these creeks. At that time, downstream flow in the creeks and in the San Rafael River is primarily irrigation-return flow and some ground-water seepage. The dissolved-solids concentrations of water at the points of major diversions on Huntington, Cottonwood, and Ferron Creeks are generally less than 500 milligrams per liter (Mundorff and Thompson, 1982, p. 11).

The dissolved-solids concentrations increase markedly toward the mouths of Huntington, Cottonwood, and Ferron Creeks. According to Mundorff and Thompson (1982, p. 12-13), much of the increase occurs as the streams cross a belt of land 10 to 15 miles wide where the Mancos Shale is exposed. This belt also is the main area of irrigated agriculture in the San Rafael River basin.

Water from most springs and mines in the coal-resource areas contains from 50-750 milligrams per liter of dissolved solids. The lithology of most of the water-bearing formation changes in short distances, and the ground-water system is complex. Some water may move relatively rapidly through fractures whereas other water may seep much more slowly through the pore spaces between sand grains of soluble material. Thus, the concentration of dissolved solids in water in each formation may be quite variable (Danielson and others, 1981, p. 34).

AVAILABLE DATA

Proposed Mining

A summary of the potential salt loads that could be contributed to the Price and San Rafael Rivers from anticipated mining appears in tables 1 and 2. These potential loads are for about 30 mines in eight drainages tributary to the Price River and 22 mines in the Cottonwood and Huntington Creek drainages tributary to the San Rafael River. The data in tables 1 and 2 were obtained from (1) compilations for six drainages by contractors while preparing Cumulative Hydrologic Impact Assessments for the Office of Surface Mining Reclamation and Enforcement, (2) information from determinations of probable hydrologic impacts in individual permit applications submitted to the Utah Division of Oil, Gas, and Mining, (3) monitoring reports for the National Pollutant Discharge Elimination System furnished to the U.S. Environmental Protection Agency, and (4) other miscellaneous monitoring data for the permit areas.

Cumulative Hydrologic Impact Assessments are not available for several of the drainages within the Price River basin where mining is anticipated. Thus, table 1 includes much data for individual mines that were calculated from information in the files of the Utah Division of Oil, Gas, and Mining. The quantity and quality of ground water that could be intercepted by the mines plus the additional salt load associated with the areas of surface disturbance were considered for the Price River basin. All significant mining in the San Rafael River basin was considered in Cumulative Hydrologic Impact Assessments as reported by Simons, Li, and Associates, Inc. (1984a and 1984b). The increased salt load from areas of surface disturbance that was projected for the San Rafael River basin was furnished by Lynn Shown (Office of Surface Mining Reclamation and Enforcement, Denver, CO, written communication, 1985). The data in table 2 pertaining to the projected quantity of ground water to be intercepted by mines in the San Rafael River basin are reported by Simons, Li, and Associates, Inc. (1984a, table 5.1 and 1984b, table 5.1).

The data for dissolved-solids load in tables 1 and 2 are for the worst-case condition using peak loads for each mine. These peak loads were assumed to occur simultaneously and were used with streamflow data available for gaging stations and miscellaneous sites as input to models to predict an upper limit of the impact on the Price and San Rafael Rivers.

Quantity and Quality of Streamflow

Price River Basin

Daily streamflow records for 11 continuous-record gaging stations in the Price River basin downstream from Scofield Reservoir were used in this study (fig. 3). The gaging stations are listed in table 3, together with period of record used, drainage area, and average streamflow. Some seasonal records are available for sites on Coal and Soldier Creeks and a few other small tributaries. In addition, streamflow and water-quality data determined for many sites on the Price River and most tributaries during 1969-70 are reported by Mundorff (1972, table 4). Including Mundorff's and other data,

Table 1.--Summary of anticipated coal mining in the Price River basin and potential dissolved-solids loading to tributary streams

[Data from Engineering-Science (1983, 1984a, 1984b, and 1984c) and information in the files of the Utah Division of Oil, Gas, and Mining.]

Drainage impacted by anticipated mining and (mines included)	Coal production, in millions of tons per year, and (anticipated life)	Projected area of surface disturbance, in acres, and (dissolved-solids load, in tons per year)	Peak ground-water discharge anticipated, in cubic feet per second	Dissolved-solids concentrations of ground-water discharge, in milligrams per liter, and (peak load, in tons per year)	Combined dissolved-solids load to tributary streams, in tons per year
Mud Creek (Belina No. 1 and 2 mines; Skyline No. 1, 2, and 3 mines; Blazon No. 1 mine; Scofield mine; Kinney No. 2 mine; O'Connor Portal; and Miller Canyon Lease Tract)	10.0 (1984-2020)	250 (1,000)	3.5	526 (1,810)	2,810
Spring Canyon, Willow Creek, and Price River (Price River Coal Complex)	2.0 (1984-2084)	219 (149)	0.25	1,600 (394)	543
Gordon Creek (Gordon Creek No. 2 mine, Southwest Lease, and C & W mine)	1.0 (1984-2003)	50 (230)	0	-- (0)	230
Deadman Creek (Pinnacle, Apex, and Aberdeen mines)	1.2 (1984-2010)	25 (100)	0	-- (0)	100
Soldier Creek (Soldier Canyon mine and Fish Creek No. 1 and 2 mines)	5.0 (1984-2020)	145 (290)	0.39	864 (332)	622
Miller Creek (King No. 4, 5, and 6 mines; Hiawatha mines complex; and Star Point No. 1 and 2 mines)	3.4 (1984-2014)	450 (1,800)	3.5	675 (2,330)	4,130
Grassy Trail Creek (Sage Point-Dugout Canyon mine, Sunnyside mine, and Geneva mine)	6.0 (1984-2030)	485 (1,940)	5.0	1,050 (5,170)	7,110
Little Park Wash (South Lease)	2.0 (1984-2020)	415 (1,660)	0	--	1,660

Table 2.--Summary of anticipated coal mining in the San Rafael River basin and potential dissolved-solids loading to tributary streams

[Data from Simons, Li, and Associates, Inc. (1984a, table 5.1, and 1984b, table 5.1); information in the files of the Utah Division of Oil, Gas, and Mining; and information furnished by Lynn Shown, Office of Surface Mining Reclamation and Enforcement, Denver, 1985.]

Drainage impacted by anticipated mining and (mines included)	Coal production, in millions of tons per year, and (anticipated life)	Projected area of surface disturbance, in acres, and (dissolved-solids load, in tons per year)	Seasonal range of peak ground-water discharge anticipated, in cubic feet per second	Dissolved-solids concentrations of ground-water discharge, in milligrams per liter, and (peak load, in tons per year)	Combined dissolved-solids load to tributary streams, in tons per year
Huntington Creek (Bear Canyon mine; Belina No. 1 and 2 mines; Crandall Canyon mine; Deer Creek mine; Huntington Canyon No. 4 mine; King Complex No. 4, 5, 6, 7, and 8 mines; Rilda Canyon mine; Skyline No. 1, 2, and 3 mines; Star Point No. 1 and 2 mines; Trail Canyon mine; and Wild Horse Ridge mine)	10.7 (1984-2034)	102 (304)	0.8-1.3	590 (581)	885
Cottonwood Creek (Des-Bee-Dove mine; Trail Mountain mine; and Wilberg mine)	3.0 (1984-2013)	158 (403)	2.1-5.4	552 (2,225)	2,628

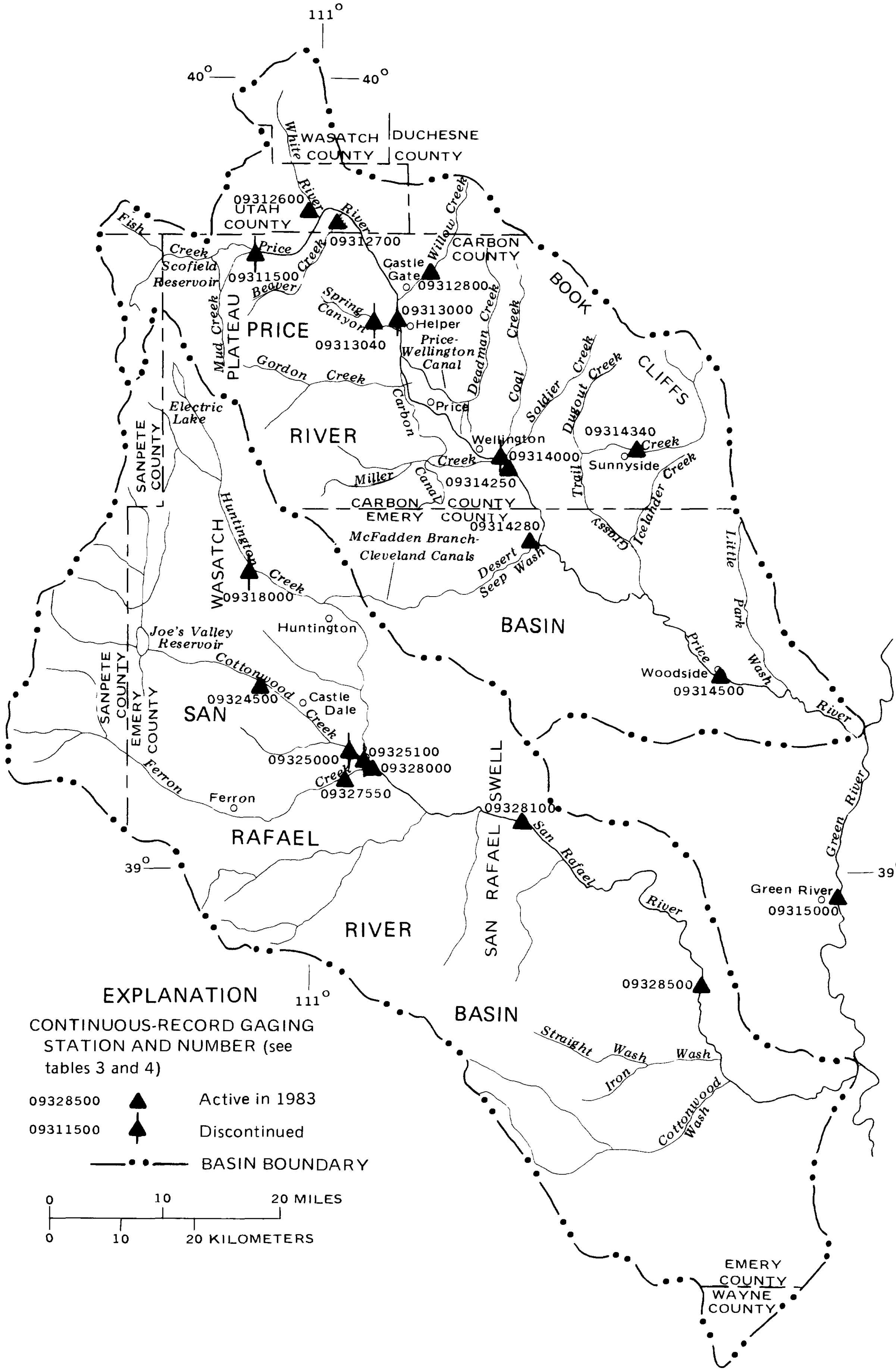

Figure 3.—Location of gaging stations used to define existing conditions for this study.

Table 3.--List of continuous-record gaging stations in the Price River basin used to determine existing conditions downstream from Scofield Reservoir

No.: See figure 3 for location of stations.

Station No.	Station Name	Period of record used (water years)	Drainage area (square miles)	Average streamflow (cubic feet per second)
09311500	Price River near Scofield	1947-68, 1980	155	61.0
09312600	White River below Tabbyune Creek, near Soldier Summit	1968-83	75.6	30.7
09312700	Beaver Creek near Soldier Summit	1961-83	26.1	4.31
09312800	Willow Creek near Castle Gate	1963-83	62.8	9.33
09313000	Price River near Heiner	1947-81 1950-58	415	112 128
09313040	Spring Canyon below Sowbelly Gulch, at Helper	1979-81	23.0	0.30
09314000	Price River near Wellington	1950-58	850	75.4
09314250	Price River below Miller Creek, near Wellington	1973-83	956	117
09314280	Desert Seep Wash near Wellington	1973-83	191	25.6
09314340	Grassy Trail Creek at Sunnyside	1979-83	40.1	10.4
09314500	Price River at Woodside	1947-83 1973-83	1,540	115 151

the number of determinations of dissolved-solids concentrations at these sites ranges from 1 to more than 100, and one or more field determinations of specific conductance are available for most of the sites.

San Rafael River Basin

Daily streamflow records for eight continuous-record gaging stations in the San Rafael River basin were used in this study (fig. 3). All the stations are downstream from the areas covered by the Cumulative Hydrologic Impact Assessments of Huntington and Cottonwood Creeks (Simons, Li, and Associates, Inc., 1984a and 1984b). The gaging stations are listed in table 4, together with period of record used, drainage area, and average streamflow. In addition, streamflow and water-quality data determined for many sites on the San Rafael River and most tributaries during 1977-78 are reported by Mundorff and Thompson (1982, table 5). The number of determinations of dissolved-solids concentrations at these sites ranges from 1 to more than 100, and one or more field determinations of specific conductance are available for most of the sites.

THE MODELING

Description of the Model

The model used for this study was written by A. W. Burns (U.S. Geological Survey, written communication, 1983) and slightly modified and described in detail by Parker and Norris (1983). The model routes streamflow and dissolved-solids load through a stream network by the use of an algorithm which is an accounting procedure that sums quantity and quality of streamflow in monthly time steps from one or more upstream points to a downstream point. The addition of quantity and quality of flow is completed at individual points called nodes. A reach is defined as a segment of stream between nodes.

Input, internal, and output nodes were used (fig. 4). Input nodes are the upstream nodes in the network (nodes 1, 2, and 3 in figure 4). The summation process of determining streamflow at a downstream point starts at these nodes; therefore, the ideal case is to have gaging-station records for the input nodes. This is not always possible, however, and some flow and water-quality data were estimated for this study.

Flow and dissolved-solids load data from upstream nodes are accumulated at internal nodes (nodes 4, 5, and 6 in figure 4). As such, results for some internal nodes are not given in this report. Internal nodes also are used to input anticipated changes in quantity and quality of flow resulting from individual coal mines or groups of mines within an individual drainage. These input changes at a node can be sources of flow from dewatering a mine or dissolved-solids loads from areas of surface disturbance. The quantity and quality of flow for several mines often were combined at a single node. Thus, there is not an internal node for every mine.

An output node is any node at which there is an interest in observing the results. For example, one may want to compare the data determined for existing conditions with that calculated for the period of anticipated mining, thereby determining potential impacts of the anticipated mining. The most

Table 4.--List of continuous-record gaging stations in the San Rafael River basin used to determine existing conditions downstream from major coal mining in the Huntington and Cottonwood Creek basins

No.: See figure 3 for location of stations.

Station No.	Station Name	Period of record used (water years)	Drainage area (square miles)	Average streamflow (cubic feet per second)
09318000[1]	Huntington Creek near Huntington	1973, 1978-81	190	93.9
09324500	Cottonwood Creek near Orangeville	1948-58 1976-83	208	98.7 100
09325000	Cottonwood Creek near Castle Dale	1948-58	261	54.8
09325100	San Rafael River above Ferron Creek, near Castle Dale	1965-70	680	94.3
09327550	Ferron Creek below Paradise Ranch, near Clawson	1976-83	221	51.6
09328000	San Rafael River near Castle Dale	1948-64 1973-83 1976-83	930	116 122
09328100	San Rafael River at San Rafael Bridge Campground, near Castle Dale	1976-83	1,284	127
09328500	San Rafael River near Green River	1948-83 1976-83	1,628	123 136

[1]Also considered records for station 09317997.

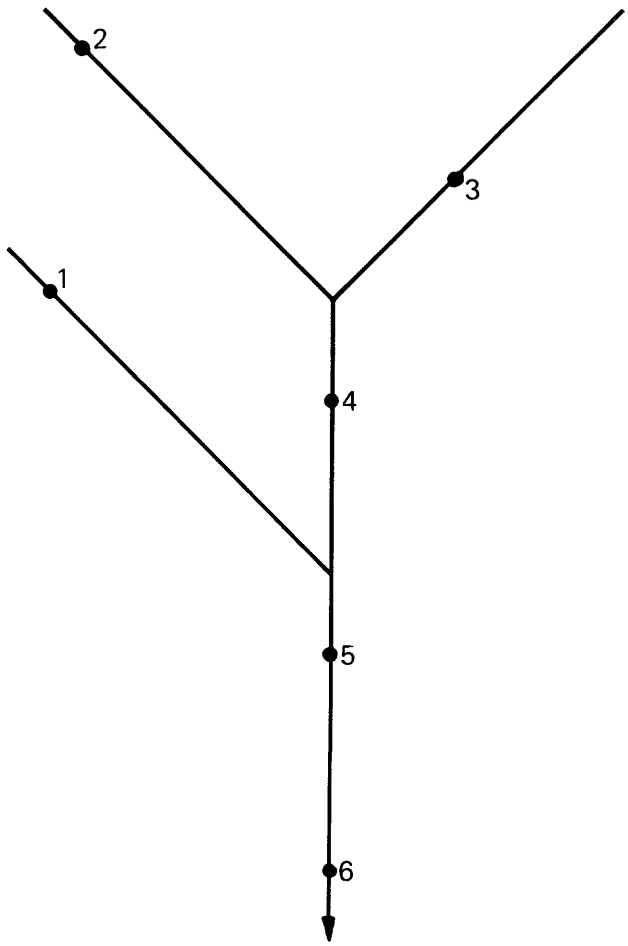

Figure 4.—Diagram of a simple stream network with nodes and node numbers for the model.

downstream node (node 6 in figure 4) usually would be an output node. If the cumulative impacts of coal mining in the area upstream of node 4 are of interest, node 4 also could be an output node.

At each output node, the component for quantity of flow, which is the mean monthly streamflow; in cubic feet per second, was calculated by the equation:

$$Q_i = \left(\sum_{u=1}^{n} Q_u\right) + Q_r, \quad (1)$$

where: Q_i = streamflow at node i,
n = number of nodes immediately upstream of node i,
Q_u = streamflow at nodes immediately upstream from node i, and
Q_r = incremental streamflow (increase or decrease) within the reach between node i and adjacent nodes immediately upstream.

At each output node, the component for quality of flow, which is the mean monthly dissolved-solids concentration, in milligrams per liter, was calculated by the mass-balance equation:

$$C_i = \left\{\left(\sum_{u=1}^{n} Q_u C_u\right) + Q_r C_r\right\} / \left\{\left(\sum_{u=1}^{n} Q_u\right) + Q_r\right\}, \quad (2)$$

where: C_i = dissolved-solids concentation at node i,
n = number of nodes immediately upstream of node i,
C_u = dissolved-solids concentration at nodes immediately upstream from node i, and
C_r = dissolved-solids concentration associated with the incremental streamflow (Q_r) within the reach.

Model for Price River Basin

Description of Nodes

A general description of the 37 nodes used for the model of the Price River basin appears in table 5. Node numbers were assigned consecutively in a downstream direction beginning with the input node on the Price River near Scofield. Nodes 2, 9, 14, 18, 22, 26, 31, and 35 represent the additional flow and dissolved-solids load contributed by one or more mines to each of eight tributary streams.

Calibration

Nodes 7, 28, and 33 are output nodes used for calibration. The mean monthly flows and the dissolved-solids concentrations are defined adequately at these locations by records for gaging stations. The quantity and quality of flows were adjusted at intermediate input nodes to minimize the difference between values computed by the model for nodes 7, 28, and 33 and values defined by records for gaging stations. The streamflows for the calibrated model of the Price River basin are listed in table 6. The relations between dissolved-solids concentrations and streamflow at nodes 7, 28, and 33 for the calibrated model are listed in table 7.

Records obtained prior to 1947 were not used because regulation at Scofield Reservoir was changed during 1945. All records for sites on the Price River were adjusted to the 1947-83 period by relating monthly flows at short-term sites to those at long-term sites. Values for flow and dissolved-solids concentration at many tributary streams were increased in relation to values observed at gaging stations because the latter were smaller than observations at the mouth of the streams.

Figure 5 shows the relation between dissolved-solids concentration and streamflow at the most downstream node used for calibration--node 33, which is station 09314500, Price River at Woodside. A comparison between values of dissolved-solids concentrations at node 33, as computed for the calibrated model, and values from the relation defined in figure 5 is given in table 8. This type of comparison gave results of similar accuracy for nodes 7 and 28 that are not tabulated in this report. In addition, the dissolved-solids load at node 33 for existing conditions was computed by the model as 284,000 tons per year, which compares to an average of 328,000 tons per year computed using data for 1952-69 reported by Mundorff (1972, table 2 and the corresponding streamflow data).

Table 5.--General description of nodes used in the model for the Price River basin

Node no.	Description
1	Station 09311500, Price River near Scofield
2	Contribution from proposed mining in the Mud Creek drainage
3	Combination of nodes 1 and 2
4	Station 09312600, White River below Tabbyune Creek, near Soldier Summit
5	Station 09312700, Beaver Creek near Soldier Summit
6	Station 09312800, Willow Creek near Castle Gate
7	Station 09313000, Price River near Heiner (combination of nodes 3, 4, 5, and 6)
8	Station 09313040, Spring Canyon below Sowbelly Gulch, at Helper
9	Contribution from proposed expansion of Price River Coal Complex
10	Combination of nodes 7, 8, and 9
11	Diversions to Price-Wellington and Carbon Canals
12	Combination of nodes 10 and 11
13	Gordon Creek at mouth
14	Contribution from mines in the Gordon Creek drainage
15	Combination of nodes 13 and 14
16	Combination of nodes 12 and 15
17	Deadman Creek at mouth
18	Contribution from proposed mining in the Deadman Creek drainage
19	Combination of nodes 17 and 18
20	Coal Creek at mouth
21	Soldier Creek at mouth
22	Contribution from proposed mining in the Soldier Creek drainage
23	Combination of nodes 21 and 22
24	Station 09314000 Price River near Wellington (combination of nodes 16, 19, 20, and 23)
25	Miller Creek at mouth
26	Contribution from proposed mining in the Miller Creek drainage
27	Combination of nodes 25 and 26
28	Station 09314250, Price River below Miller Creek, near Wellington (combination of nodes 24 and 27)
29	Station 09314280, Desert Seep Wash near Wellington
30	Grassy Trail Creek at mouth

Table 5.--General description of nodes used in the model for the Price River basin--Continued

Node no.	Description
31	Contribution from proposed mining in the Grassy Trail Creek drainage
32	Combination of nodes 30 and 31
33	Station 09314500, Price River at Woodside (combination of nodes 28, 29, and 32)
34	Little Park Wash at mouth
35	Contribution from proposed mining in the Little Park Wash drainage
36	Combination of nodes 34 and 35
37	Price River at mouth (combination of nodes 33 and 36)

Table 6.--Mean monthly streamflow at nodes for the Price River basin as determined by the calibrated model

Station: Descriptive name given for sites where station numbers are not available.

Node	Station	Mean monthly streamflow (cubic feet per second)											
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
1	09311500	36.4	9.2	7.4	3.1	2.5	3.7	24.8	93.1	201	193	127	91.2
4	09312600	7.1	5.9	5.8	6.3	8.8	23.1	100.5	191	59	14.2	10.7	4.0
5	09312700	1.0	.7	.9	.9	1.6	2.5	8.2	24.9	12.9	2.5	1.5	.3
6	09312800	2.3	1.3	1.0	1.4	2.4	8.9	35.5	54.0	16.1	5.3	4.8	.8
7	09313000	46.8	17.1	15.1	11.7	15.3	38.2	169.0	363	289	215	144	96.3
8	09313040	.4	.5	.4	.5	.5	.2	.2	.3	.2	.2	.3	.3
11	Diversions to Price-Wellington and Carbon Canals	(15.0)[1]	(0)	(0)	(0)	(0)	(0)	(128.4)	(238.7)	(213.5)	(183.1)	(80.3)	(42.1)
13	Gordon Creek at mouth	3.5	5.0	4.0	5.1	6.9	11.3	40.0	70.0	25.0	7.0	5.2	1.0
17	Deadman Creek at mouth	1.1	1.4	1.0	1.3	1.8	1.6	10.2	21.8	9.9	3.1	1.7	1.7
20	Coal Creek at mouth	2.0	2.5	1.8	2.3	3.2	2.9	18.4	35.0	17.9	5.6	3.1	3.1
21	Soldier Creek at mouth	1.4	1.7	1.3	1.6	2.3	2.0	12.9	27.6	12.5	3.9	2.2	2.2
24	09314000	40.2	28.2	23.6	22.5	30.0	56.2	122.3	279.0	141.0	51.7	76.2	62.5
25	Miller Creek at mouth	6.0	5.4	2.7	.6	10.0	10.0	10.0	10.0	10.0	6.2	6.0	6.0
28	09314250	46.2	33.6	26.3	23.1	40.0	66.2	132.3	289	151.0	57.9	82.2	68.5
29	09314280	33.2	25.4	11.6	8.6	15.4	30.5	21.7	25.0	33.0	33.2	33.0	33.5
30	Grassy Trail Creek at mouth	2.0	1.8	1.5	1.3	1.2	1.9	7.0	15.0	44.0	7.8	3.8	3.0
33	09314500	81.4	60.8	39.4	33.0	56.6	98.6	161.0	329.0	228.0	98.9	119.0	105.0
34	Little Park Wash at mouth	.3	.3	.4	.4	.6	1.0	3.0	9.0	5.0	1.0	.6	.1
37	Price River at mouth	81.7	61.1	39.8	33.4	57.2	99.6	164.0	338.0	233.0	99.9	119.6	105.1

[1]All values in parentheses are used as negative numbers in the model.

Table 7.--Summary of relations between dissolved-solids concentrations (DS) and streamflow (Q) at output nodes used for calibration of the Price River basin model

Node no.	Station no.	Equation	Number of observations	Standard error (percent)
7	09313000	$DS = 743\ Q^{-0.20}$	44	25
28	09314250	$DS = 5{,}296\ Q^{-0.33}$	12	18
33	09314500	$DS = 11{,}630\ Q^{-0.33}$	900	34

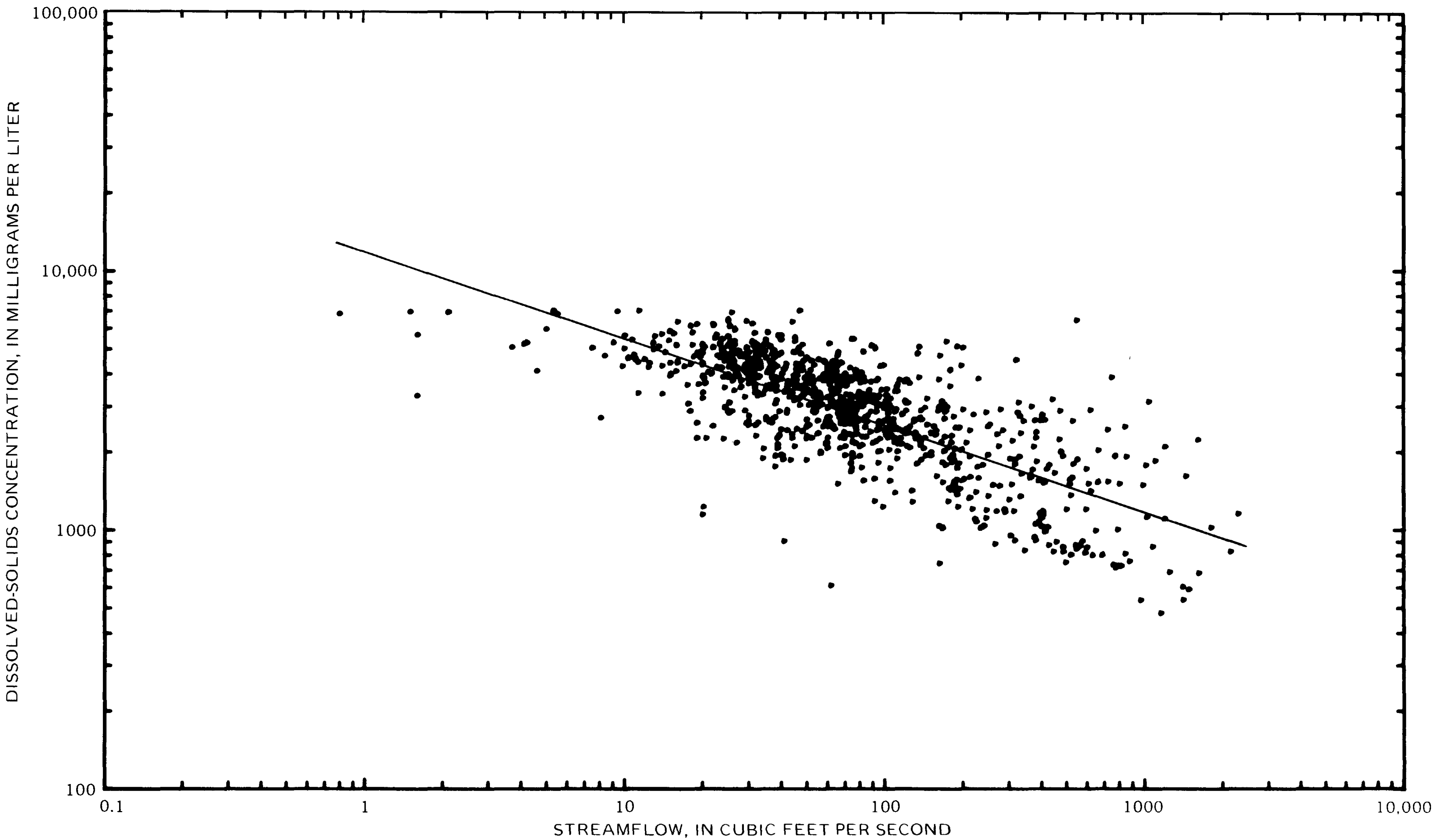

Figure 5.—Relation between dissolved-solids concentration and streamflow at station 09314500, Price River at Woodside.

Table 8.--Comparison for node 33 of dissolved-solids concentrations computed from the calibrated model of the Price River basin with values obtained by relating dissolved-solids concentration to streamflow

Month	Dissolved-solids concentration, in milligrams per liter	
	Computed from model	Computed from relation appearing in table 7
Oct	3,119	2,723
Nov	3,708	2,998
Dec	3,663	3,460
Jan	3,714	3,668
Feb	3,566	3,070
Mar	2,850	2,556
Apr	2,390	2,174
May	1,763	1,718
June	1,943	1,938
July	2,928	2,554
Aug	2,288	2,402
Sept	2,478	2,504

Model for San Rafael River Basin

Description of Nodes

A general description of the 13 nodes used for the model of the San Rafael River basin appears in table 9. Node numbers were assigned consecutively in a downstream direction beginning with the input node at station 09318000, Huntington Creek near Huntington, which is at the most downstream point considered in the Cumulative Hydrologic Impact Assessment of the Huntington Creek drainage (Simons, Li, and Associates, Inc., 1984a). Nodes 2 and 7 represent the additional flow and dissolved-solids load contributed by tributaries of Huntington and Cottonwood Creeks from all anticipated mining within these drainages.

Calibration

Nodes 11 and 13 are output nodes used for calibration. The mean monthly flows and dissolved-solids concentrations at nodes 11 and 13 are defined adequately by records for gaging stations. The quantity and quality of flows were adjusted at intermediate input nodes to minimize the differences between values computed by the model for nodes 11 and 13 and values defined by records for gaging stations. The streamflows for the calibrated model of the San Rafael River basin are listed in table 10. The relations between dissolved-solids concentrations and streamflow at nodes 11 and 13 for the calibrated model are listed in table 11.

Records obtained prior to 1948 were not used for the gaging stations because diversions before 1948 appear to be different than those since 1948. For Huntington Creek, more weight was given to records obtained after 1973 because diversions and regulation of Huntington Creek changed in order to operate the Utah Power and Light Co. Huntington Plant, which diverts flow from the Creek about 2 miles upstream from station 09318000.

Figure 6 shows the relation between dissolved-solids concentration and streamflow at the most downstream node used for calibration--node 13, which is station 09328500, San Rafael River near Green River. A comparison between values of dissolved-solids concentrations at node 13, as computed for the calibrated model, and values from the relation defined in figure 6 is given in table 12. This type of comparison also was made for node 11, and although the results are just as accurate, they are not tabulated in this report.

Table 9.--General description of nodes used in the model for the San Rafael River basin

Node no.	Description
1	Station 09318000, Huntington Creek near Huntington
2	Contribution from proposed mining in the Huntington Creek drainage as reported by Simons, Li, and Associates, Inc. (1984a, table 5.1), and Lynn Shown, Office of Surface Mining Reclamation and Enforcement, Denver, 1985
3	Combination of nodes 1 and 2
4	Diversions from Huntington Creek to McFadden Branch Canal-Cleveland Canal
5	Huntington Creek at mouth (combination of nodes 3 and 4)
6	Station 09324500, Cottonwood Creek near Orangeville
7	Contribution from proposed mining in the Cottonwood Creek drainage as reported by Simons, Li, and Associates, Inc. (1984b, table 5.1), and Lynn Shown, Office of Surface Mining Reclamation and Enforcement, Denver, 1985
8	combination of nodes 6 and 7
9	Diversions from Cottonwood Creek between station 09324500 and mouth
10	Cottonwood Creek at mouth (combination of nodes 8 and 9)
11	Station 09325100, San Rafael River above Ferron Creek, near Castle Dale (combination of nodes 5 and 10)
12	Station 09327550, Ferron Creek below Paradise Ranch, near Clawson
13	Station 09328500, San Rafael River near Green River (combination of nodes 11 and 12)

Table 10.--Mean monthly streamflow at nodes for the San Rafael River basin as determined by the calibrated model

Station: Descriptive name given for sites where station numbers are not available.

Node	Station	Mean monthly streamflow (cubic feet per second)											
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
1	09318000	43.3	28.5	25.0	25.7	28.0	29.3	56.2	253	331	126	111	71.2
4	Diversions to McFadden Branch-Cleveland Canals	(43.3)[1]	(0)	(0)	(0)	(0)	(0)	(13.3)	(133)	(197)	(112)	(111)	(71.2)
6	09324500	77.9	16.9	14.9	14.3	16.9	27.1	61.5	136	361	217	135	120
9	Diversions between Station 09324500 and mouth	(19.8)	(10.0)	(9.7)	(10.0)	(10.0)	(10.2)	(32.9)	(130)	(145)	(89.2)	(60.8)	(52.0)
11	09325100	58.1	35.4	30.2	30.0	34.9	46.2	71.5	126	350	141.8	74.2	68.0
12	09327550	11.8	10.6	8.6	7.0	10.5	10.0	8.3	42.9	384	86.0	23.8	19.4
13	09328500	69.9	46.0	38.8	37.0	45.4	56.2	79.8	168.9	734	227.8	98.0	87.4

[1]All values in parentheses are used as negative numbers in the model.

Table 11.--Summary of relations between dissolved-solids concentrations (DS) and streamflow (Q) at output nodes used for calibration of the San Rafael River basin model

Node no.	Station no.	Equation	Number of observations	Standard error (percent)
11	09325100	$DS = 3,370\ Q^{-0.15}$	5	56
13	09328500	$DS = 7,030\ Q^{-0.28}$	1,280	32

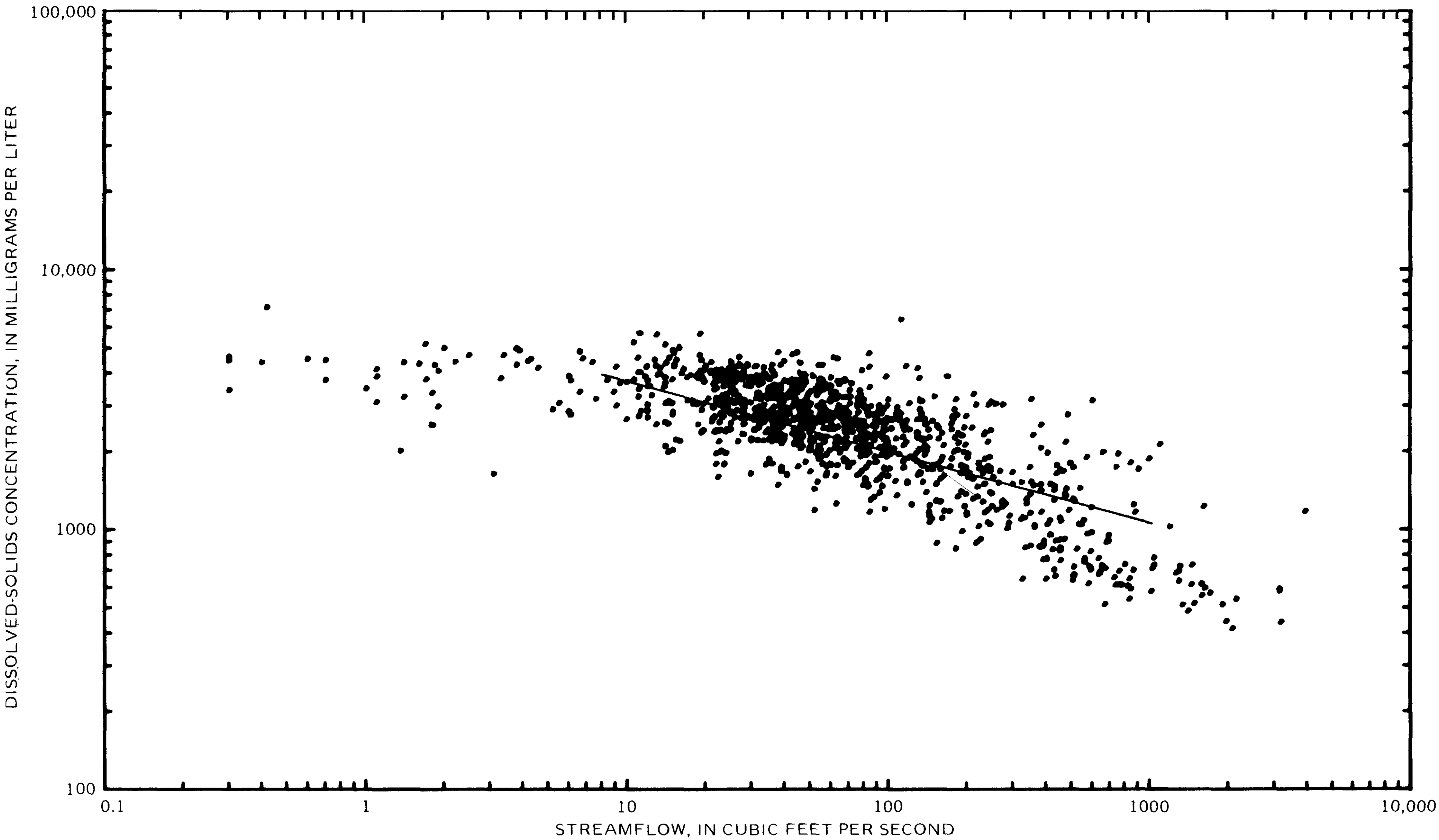

Figure 6.—Relation between dissolved-solids concentration and streamflow at station 09328500, San Rafael River near Green River.

Table 12.--Comparison for node 13 of dissolved-solids concentrations computed from the calibrated model of the San Rafael River basin with values obtained by relating dissolved-solids concentration to streamflow

Month	Dissolved-solids concentration, in milligrams per liter	
	Computed from model	Computed from relation appearing in table 11
Oct	2,175	2,140
Nov	2,271	2,406
Dec	2,325	2,524
Jan	2,352	2,558
Feb	2,276	2,415
Mar	2,318	2,275
Apr	2,196	2,063
May	1,649	1,672
June	1,179	1,108
July	1,589	1,538
Aug	1,935	1,947
Sept	1,996	2,011

POTENTIAL CHANGES IN QUANTITY AND QUALITY

OF STREAMFLOW RESULTING FROM MINING

Price River Basin

The potential cumulative impacts of anticipated coal mining on the quantity and quality of mean monthy flow in the Price River are summarized in tables 13, 14, 15, and 16. The results in table 16 were computed with the assumption that the peak or maximum quantity of ground water intercepted by and discharged from each mine occurred simultaneously for all mines in the eight drainages listed in table 1. Thus, a worst-case condition is presented.

As shown in table 13, the increase in mean monthly flow downstream from Scofield Reservoir is projected as 3.5 cubic feet per second, ranging from 1.7 percent in June to 140 percent in February. The potential increase in dissolved-solids concentration would range from 10.4 percent in June and July (from 202 to 223 milligrams per liter) to 97.0 percent in February (from 202 to 398 milligrams per liter). Although the largest increase in dissolved-solids concentration is projected as 97.0 percent in February, the concentration of the mixture of mine water with the existing flow released from Scofield Reservoir would contain less than 500 milligrams per liter of dissolved solids.

For existing (1983) conditions in the Price River basin, the water quality deteriorates downstream, and water entering the Price River from tributaries downstream from Beaver Creek generally contains greater dissolved-solids concentrations than does the additional ground water that would be discharged from anticipated future mining. Thus, the additional quantity of flow from the mines would decrease the dissolved-solids concentrations for some months at downstream locations. For example, at the mouth of the Price River, the increase in mean monthly flow is projected as 12.6 cubic feet per second (table 16), ranging from 3.7 percent in May to 37.7 percent in January. The projected dissolved-solids load from mining ranges from 944 tons in January to 2,741 tons in June, and the changes in dissolved-solids concentration range from a 20.7 percent decrease in January (from 3,677 to 2,917 milligrams per liter) to a 1.3 percent increase in June (from 1,911 to 1,935 milligrams per liter). This reflects the smaller dissolved-solids concentrations in the additional anticipated ground water from the mines as compared to that of the tributary inflow in the downstream Price River basin. In comparison, at the Price River just upstream from the diversions to the Price-Wellington and Carbon Canals, the increase in mean monthly flow is projected as 3.8 cubic feet per second (table 14), ranging from an increase of 1.0 percent in May to 31.1 percent in January. The increase of dissolved-solids concentration ranges from 2.7 percent in January (from 598 to 614 milligrams per liter) to 12.2 percent in September (from 238 to 267 milligrams per liter).

Table 13.--Maximum potential changes in streamflow and dissolved-solids concentration in the Price River at station 09311500, Price River near Scofield, node 1, resulting from ground-water discharge from the mines and additional salt load from areas of surface disturbance

Month	Existing conditions			Contribution from mining		Combined flow and dissolved-solids concentration				
	Mean monthly stream-flow (cubic feet per second)	Average dissolved-solids concentration (milligrams per liter)	Dissolved-solids load (tons)	Maximum flow (cubic feet per second)	Dissolved-solids load (tons)	Mean monthly stream-flow (cubic feet per second)	Average dissolved-solids concentration (milligrams per liter)	Dissolved-solids load (tons)	Increase in flow (percent)	Change in dissolved-solids concentration (percent)
Oct	36.4	202	604	3.5	197	39.9	244	801	9.6	20.8
Nov	9.2	202	153	3.5	163	12.7	303	316	38.0	50.0
Dec	7.4	202	123	3.5	160	10.9	316	283	47.3	56.4
Jan	3.1	202	51.5	3.5	155	6.6	380	206	113	88.1
Feb	2.5	202	41.5	3.5	154	6.0	398	196	140	97.0
Mar	3.7	202	61.4	3.5	156	7.2	367	217	94.6	81.7
Apr	24.8	202	412	3.5	182	28.3	256	594	14.1	26.7
May	93.1	202	1,546	3.5	268	96.6	229	1,814	3.8	13.4
June	201.0	202	3,337	3.5	405	204.5	223	3,742	1.7	10.4
July	193.0	202	3,204	3.5	395	196.5	223	3,599	1.8	10.4
Aug	127.0	202	2,108	3.5	311	130.5	226	2,419	2.8	11.9
Sept	91.2	202	1,514	3.5	266	94.7	229	1,780	3.8	13.4

Table 14.—Maximum potential changes in streamflow and dissolved-solids concentration in the Price River just upstream of diversions to Price-Wellington and Carbon Canals, node 10, resulting from ground-water discharge from the mines and additional salt load from areas of surface disturbance

Month	Existing conditions			Contribution from mining		Combined flow and dissolved-solids concentration				
	Mean monthly stream-flow (cubic feet per second)	Average dissolved-solids concentration (milligrams per liter)	Dissolved-solids load (tons)	Maximum flow (cubic feet per second)	Dissolved-solids load (tons)	Mean monthly stream-flow (cubic feet per second)	Average dissolved-solids concentration (milligrams per liter)	Dissolved-solids load (tons)	Increase in flow (percent)	Change in dissolved-solids concentration (percent)
Oct	47.2	312	1,209	3.8	245	51.0	347	1,454	8.1	11.2
Nov	17.6	467	676	3.8	215	21.4	507	891	21.6	8.6
Dec	15.5	482	615	3.8	208	19.3	519	823	24.5	7.7
Jan	12.2	598	600	3.8	207	16.0	614	807	31.1	2.7
Feb	15.8	571	742	3.8	206	19.6	589	948	24.1	3.2
Mar	38.4	443	1,398	3.8	197	42.2	460	1,595	9.9	3.8
Apr	169.2	303	4,211	3.8	223	173.0	312	4,434	2.2	3.0
May	363.3	251	7,483	3.8	312	367.1	259	7,795	1.0	3.2
June	289.2	248	5,893	3.8	446	293.0	264	6,339	1.3	6.5
July	215.2	235	4,164	3.8	436	219.0	256	4,600	1.8	8.9
Aug	144.3	248	2,937	3.8	355	148.1	271	3,292	2.6	9.3
Sept	96.6	238	1,889	3.8	310	100.4	267	2,199	3.9	12.2

Table 15.--Maximum potential changes in streamflow and dissolved-solids concentration in the Price River near Wellington just upstream from Miller Creek, node 24, resulting from ground-water discharge from the mines and additional salt load from areas of surface disturbance

Month	Existing conditions			Contribution from mining		Combined flow and dissolved-solids concentration				
	Mean monthly streamflow (cubic feet per second)	Average dissolved-solids concentration (milligrams per liter)	Dissolved-solids load (tons)	Maximum flow (cubic feet per second)	Dissolved-solids load (tons)	Mean monthly streamflow (cubic feet per second)	Average dissolved-solids concentration (milligrams per liter)	Dissolved-solids load (tons)	Increase in flow (percent)	Change in dissolved-solids concentration (percent)
Oct	40.2	873	2,885	4.1	285	44.3	859	3,126	10.2	-1.6
Nov	28.2	1,409	3,265	4.1	258	32.3	1,327	3,523	14.5	-5.8
Dec	23.6	1,374	2,666	4.1	248	27.7	1,280	2,914	17.4	-6.8
Jan	22.5	1,680	3,106	4.1	250	26.6	1,535	3,355	18.2	-8.6
Feb	30.0	1,639	4,041	4.1	255	34.1	1,532	4,295	13.7	-6.5
Mar	56.2	1,101	5,087	4.1	249	60.3	1,077	5,336	7.3	-2.2
Apr	122.3	1,603	16,114	4.1	370	126.4	1,577	16,388	3.4	-1.6
May	279.0	1,328	30,456	4.1	578	283.1	1,327	30,880	1.5	-0.1
June	141.0	1,297	15,031	4.1	573	145.1	1,286	15,334	2.9	-0.8
July	51.7	1,234	5,241	4.1	493	55.8	1,184	5,431	7.9	-4.1
Aug	76.2	682	4,269	4.1	402	80.3	685	4,519	5.4	0.4
Sept	62.5	623	3,202	4.1	351	66.6	631	3,453	6.6	1.3

Table 16.--Maximum potential changes in streamflow and dissolved-solids concentration in the Price River at mouth, node 37, resulting from ground-water discharge from the mines and additional salt load from areas of surface disturbance

Month	Existing conditions			Contribution from mining		Combined flow and dissolved-solids concentration				
	Mean monthly streamflow (cubic feet per second)	Average dissolved-solids concentration (milligrams per liter)	Dissolved-solids load (tons)	Maximum flow (cubic feet per second)	Dissolved-solids load (tons)	Mean monthly streamflow (cubic feet per second)	Average dissolved-solids concentration (milligrams per liter)	Dissolved-solids load (tons)	Increase in flow (percent)	Change in dissolved-solids concentration (percent)
Oct	81.7	3,110	20,880	12.6	1,105	94.3	2,830	21,942	15.4	-9.0
Nov	61.1	3,693	18,547	12.6	1,062	73.7	3,237	19,610	20.6	-12.3
Dec	39.8	3,632	11,881	12.6	995	52.4	2,990	12,877	31.7	-17.7
Jan	33.4	3,677	10,094	12.6	944	46.0	2,917	11,039	37.7	-20.7
Feb	57.2	3,535	16,619	12.6	1,169	69.8	3,099	17,789	22.0	-12.3
Mar	99.6	2,826	23,136	12.6	1,209	112.2	2,639	24,346	12.7	-6.6
Apr	164.0	2,355	31,738	12.6	1,590	176.6	2,289	33,234	7.7	-2.8
May	338.0	1,728	47,998	12.6	2,432	350.6	1,745	50,279	3.7	1.0
June	233.0	1,911	36,596	12.6	2,741	245.6	1,935	39,070	5.4	1.3
July	99.9	2,904	23,845	12.6	1,496	112.5	2,707	25,038	12.6	-6.8
Aug	119.6	2,279	22,403	12.6	1,284	132.2	2,165	23,536	10.5	-5.0
Sept	105.1	2,476	21,390	12.6	1,178	117.7	2,322	22,470	12.0	-6.2

San Rafael River Basin

The potential cumulative impacts of anticipated coal mining on the quantity and quality of mean monthly flow in the San Rafael River are summarized in table 17. The results in table 17 were computed with the assumption that the peak or maximum quantity of ground water intercepted by and discharged from each mine as listed in table 2 occurred simultaneously for all mines in the Huntington and Cottonwood Creek drainages. Again, a worst-case condition is presented.

As shown in table 17, the projected increase in mean monthly flow at the mouth of the San Rafael River would range from 2.9 cubic feet per second in February to 6.7 cubic feet per second in May. The increase in existing mean monthly flow would range from 0.8 percent in June to 12.6 percent in November. The projected dissolved-solids load from mining ranges from 145 tons in February to 497 tons in June, and the changes in dissolved-solids concentration of the flow at the mouth of the San Rafael River ranges from a 5.3 percent decrease in March (from 2,318 to 2,195 milligrams per liter) to a 0.6 percent increase in May (from 1,649 to 1,659 milligrams per liter). As in the Price River basin, the quality of flow deteriorates downstream in many of the tributaries, such as Huntington, Cottonwood, and Ferron Creeks, and in the San Rafael River itself. The deterioration is due primarily to solution of minerals from the Mancos Shale and return flow from irrigation. The flow in the downstream reaches of these streams contains greater dissolved-solids concentrations than does the additional ground water that would be discharged during future mining. Thus, the additional quantity of flow generally would decrease the dissolved-solids concentrations of flow at the mouth of the San Rafael River.

Table 17.--Maximum potential changes in streamflow and dissolved-solids concentration in the San Rafael River near mouth, node 13, resulting from ground-water discharge from the mines and additional salt load from areas of surface disturbance

Month	Existing conditions			Contribution from mining		Combined flow and dissolved-solids concentration				
	Mean monthly stream-flow (cubic feet per second)	Average dissolved-solids concentration (milli-grams per liter)	Dissolved-solids load (tons)	Maximum flow (cubic feet per second)	Dissolved-solids load (tons)	Mean monthly stream-flow (cubic feet per second)	Average dissolved-solids concentration (milli-grams per liter)	Dissolved-solids load (tons)	Increase in flow (percent)	Change in dissolved-solids concentration (percent)
Oct	69.9	2,175	12,490	5.5	289	75.4	2,106	13,050	7.9	-3.2
Nov	46.0	2,271	8,586	5.8	277	51.8	2,178	9,272	12.6	-4.1
Dec	38.8	2,325	7,413	4.4	212	43.2	2,244	7,968	11.3	-3.5
Jan	37.0	2,352	7,153	3.3	163	40.3	2,287	7,574	8.9	-2.8
Feb	45.4	2,276	8,491	2.9	145	48.3	2,226	8,837	6.4	-2.2
Mar	56.2	2,318	10,710	6.4	308	62.6	2,195	11,290	11.4	-5.3
Apr	79.8	2,196	14,400	6.3	322	86.1	2,137	15,120	7.9	-2.7
May	168.9	1,649	22,880	6.7	419	175.6	1,659	23,930	4.0	0.6
June	734.0	1,179	71,130	5.7	497	739.7	1,181	71,760	0.8	0.2
July	227.8	1,589	29,760	4.5	311	232.3	1,585	30,270	2.0	-0.3
Aug	98.0	1,935	15,590	4.2	266	102.2	1,916	16,100	4.3	-1.0
Sept	87.4	1,996	14,330	5.4	304	92.8	1,961	14,950	6.2	-1.8

Green River

The anticipated mining in the Price and San Rafael River basins should have little if any impact on the quantity and quality of flow in the Green River. The combined average flow of the Price and San Rafael Rivers at their mouths is about 270 cubic feet per second, which is about 4 percent of the average flow in the Green River. The projected peak increase in the combined flow of the Price and San Rafael Rivers would be about 18 cubic feet per second (average of all mines as listed in tables 16 and 17), which is less than 0.3 percent of the average flow of 6,316 cubic feet per second for station 09315000, Green River at Green River (ReMillard and others, 1984, p. 185).

The combined annual dissolved-solids load from the anticipated mining in the Price and San Rafael River basins is projected as about 20,700 tons (sum of right hand columns in tables 1 and 2). This represents less than 0.8 percent of the average annual dissolved-solids load of 2.7 million tons as reported by the U.S. Geological Survey (1964, table 19) for the Green River at Green River. Thus, it would be difficult to detect any change in dissolved-solids concentrations of the Green River, especially when the additional water from the mines is included.

SUMMARY

Accounting models of the quantity and quality of streamflow were developed for the Price and San Rafael River basins. The models were calibrated with streamflow records for selected gaging stations. Values at input nodes were adjusted to minimize the differences between those computed by the models and values obtained by relating dissolved-solids concentration to flow.

The increase in mean monthly flow downstream from Scofield Reservoir is projected as 3.5 cubic feet per second, ranging from 1.7 percent in June to 140 percent in February. The potential increase in dissolved-solids concentration downstream from Scofield Reservoir would range from 10.4 percent in June and July (from 202 to 223 milligrams per liter) to 97.0 percent in February (from 202 to 398 milligrams per liter). However, the concentration of the mixture of mine water with the existing flow released from Scofield Reservoir would contain less than 500 milligrams per liter of dissolved solids.

At the mouth of the Price River, the potential increase in mean monthly flow because of mining is projected as 12.6 cubic feet per second ranging from 3.7 percent in May to 37.7 percent in January. The potential changes in dissolved-solids concentration would range from a 20.7 percent decrease in January (from 3,677 to 2,917 milligrams per liter) to a 1.3 percent increase in June (from 1,911 to 1,935 milligrams per liter).

At the mouth of the San Rafael River, the potential increase in mean monthly flow ranges from 2.9 cubic feet per second in February to 6.7 cubic feet per second in May, with the increase ranging from 0.8 percent in June to 12.6 percent in November. The potential change in dissolved-solids concentration would range from a 5.3 percent decrease in March (from 2,318 to 2,195 milligrams per liter) to a 0.6 percent increase in May (from 1,649 to 1,659 milligrams per liter).

The anticipated mining in the Price and San Rafael River basins is not expected to cause a detectable change in the quantity and quality of flow in the Green River. The combined average flow of the Price and San Rafael Rivers is about 4 percent of the average flow in the Green River. The projected peak increase in flow resulting from discharge from the mines is less than 0.3 percent of the average flow in the Green River. The combined dissolved-solids load from the anticipated mining in the Price and San Rafael River basins represents less than 0.8 percent of the average annual dissolved-solids load of the Green River. Thus, it would be hard to detect any change in the dissolved-solids concentrations of the Green River.

REFERENCES CITED

Blackman, W. C., Jr., Rouse, J. V., Schillinger, G. R., and Shafer, W. H., Jr., 1973, Mineral pollution in the Colorado River Basin: Journal Water Pollution Control Federation, v. 45, no. 7, pp. 1517-1557.

Danielson, T. W., ReMillard, M. D., and Fuller, R. H., 1981, Hydrology of the coal-resource areas in the upper drainages of Huntington and Cottonwood Creeks, central Utah: U.S. Geological Survey Water-Resources Investigations Report 81-539, 85 p.

Engineering-Science, 1983, Cumulative hydrologic impact assessment with respect to Valley Camp of Utah's Belina Mine: Engineering-Science, Denver, Colorado, 69 p., 4 appendices.

_____1984a, Cumulative hydrologic impact assessment with respect to the Gordon Creek No. 2 Mine: Engineering-Science, Denver, Colorado, 50 p., 1 appendix.

_____1984b, Cumulative hydrologic impact assessment with respect to the Hiawatha mines complex: Engineering-Science, Denver, Colorado, 90 p., 2 appendices.

_____1984c, Cumulative hydrologic impact assessment with respect to the Soldier Canyon Mine: Engineering-Science, Denver, Colorado, 35 p.

Farnsworth, R. K., Thompson, E. S., and Peck, E. L., 1982, Evaporation Atlas for the Contiguous 48 United States: National Oceanic and Atmospheric Administration Technical Report NWS 33, 27 p.

Fenneman, N. M., 1946, Physical divisions of the United States: U.S. Geological Survey Map, scale 1:7,000,000.

Hintze, L. F., {compiler}, 1980, Geologic map of Utah: Utah Geological and Mineral Survey, 2 sheets, scale 1:500,000.

Lines, G. C., and Plantz, G. G., 1981, Hydrologic monitoring in the coal fields of central Utah, August 1978-September 1979: U.S. Geological Survey Water-Resources Investigations Report 81-138, 56 p.

Mundorff, J. C., 1972, Reconnaissance of chemical quality of surface water and fluvial sediment in the Price River basin, Utah: Utah Department of Natural Resources Technical Publication 39, 55 p.

Mundorff, J. C., and Thompson, K. R., 1982, Reconnaissance of the quality of surface water in the San Rafael River basin, Utah: Utah Department of Natural Resources Technical Publication 72, 53 p.

Parker, R. S., and Norris, J. M., 1983, Simulated effects of anticipated coal mining on dissolved solids in selected tributaries of the Yampa River, northwestern Colorado: U.S. Geological Survey Water-Resources Investigations Report 83-4084, 66 p.

ReMillard, M. D., and others, 1984, Water Resources Data, Utah, water year 1983: U.S. Geological Survey Water-Data Report UT-83-1, 489 p.

Simons, Li, and Associates, Inc., 1984a, Cumulative hydrologic impact assessment, Huntington Creek basin, Emery County, Utah: Simons, Li, and Associates, Inc., Fort Collins, Colorado, 132 p.

_____1984b, Cumulative hydrologic impact assessment, Cottonwood Creek basin, Emery County, Utah: Simons, Li, and Associates, Inc., Fort Collins, Colorado, 125 p.

U.S. Geological Survey, 1964, Mineral and water resources of Utah: Utah Geological and Mineralogical Survey Bulletin 73, 275 p.

U.S. Weather Bureau, [1963], Normal annual precipitation (1931-60) for the State of Utah: Map of Utah, scale 1:500,000.