UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

HYDROLOGIC RECONNAISSANCE OF THE WASATCH PLATEAU-BOOK CLIFFS COAL-FIELDS AREA, UTAH

Open-File Report 79-988

Prepared in cooperation with the
U.S. Bureau of Land Management
and the U.S. Environmental
Protection Agency

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By K. M. Waddell, P. Kay Contratto, C. T. Sumsion, and J. R. Butler

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Salt Lake City, Utah

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METRIC CONVERSION FACTORS

Most measurements in this report are given in the inch-pound system of units. The conversion factors for computing metric equivalents are shown below.

Inch-pound system Unit (Multiply)	Inch-pound system Abbreviation	(by)	Metric system Unit (to obtain)	Metric system Abbreviation
Acre		0.4047	Square hectometer	hm^2
		0.004047	Square kilometer	km^2
Acre-foot	acre-ft	0.001233	Cubic hectometer	hm^3
		1233	Cubic meter	m^3
Cubic foot per second	ft^3/s	0.02832	Cubic meter per second	m^3/s
Foot	ft	0.3048	Meter	m
Gallon per minute	gal/min	0.06309	Liter per second	L/s
Inch	in.	25.40	Millimeter	mm
		2.540	Centimeter	cm
Mile	mi	1.609	Kilometer	km
Square mile	mi^2	2.590	Square kilometer	km^2

Chemical concentration and water temperature are given only in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (μg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is about the same as for concentrations in the inch-pound unit, parts per million.

Chemical concentrations in terms of ionic interacting values is given in milliequivalents per liter (meq/L). Meq/L is numerically equal to the inch-pound unit, equivalents per million.

Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation: $°F = 1.8(°C) + 32$.

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Abstract

Data obtained during a hydrologic reconnaissance in 1975-77 in the Wasatch Plateau-Book Cliffs coal area of Utah were correlated with existing long-term data. Maps were prepared showing average precipitation, average streamflow, stream temperature, ground- and surface-water quality, sediment yield, and geology. Recommendations were made for additional study and suggested approaches for continued monitoring in the coal areas.

During the 1931-75 water years, the minimum discharges for the five major streams that head in the area ranged from about 12,000 to 26,000 acre-feet per year, and the maximum discharges ranged from about 59,000 to 315,000 acre-feet per year. Correlations indicate that 3 years of low-flow records at stream sites in the Wasatch Plateau would allow the development of relationships with long-term sites that can be used to estimate future low-flow records within a standard error of about 20 percent.

Most water-quality degradation in streams occurs along the flanks of the Wasatch Plateau and Book Cliffs. In the uplands, dissolved-solids concentrations generally ranged from less than 100 to about 250 milligrams per liter, and in the lowlands the concentrations ranged from about 250 to more than 6,000 milligrams per liter.

Most springs in the Wasatch Plateau and Book Cliffs discharge from the Star Point Sandstone or younger formations, and the water generally contains less than about 1,000 milligrams per liter of dissolved solids. The discharges of 65 springs ranged from about 0.2 to 200 gallons per minute. The Blackhawk Formation, which is the principal coal-bearing formation, produces water in many of the mines. The dissolved-solids concentration in water discharging from springs and mines in the Blackhawk ranged from about 60 to 800 milligrams per liter.

In the lowland areas, the Ferron Sandstone Member of the Mancos Shale appears to have the most potential for subsurface development of water of suitable chemical quality for human consumption. Three wells in the Ferron yielded water with dissolved-solids concentrations ranging from about 650 to 1,230 milligrams per liter.

Introduction

The U.S. Geological Survey, in cooperation with the U.S. Bureau of Land Management, conducted a reconnaissance from July 1975 to September 1977, which was designed to provide an assessment of the hydrology of the Wasatch Plateau-Book Cliffs coal-fields area in Utah. The U.S. Environmental Protection Agency also supported the study by providing additional funds for enhancement of the water-quality effort. The coal lands in Utah are largely in the Upper Colorado River Basin (fig. 1). The most active coal-mining areas in 1977 were

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Figure 1 (caption on next page) near here

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in the Wasatch Plateau and Book Cliffs area.

The objectives of the study were to (1) establish data bases for hydrologic parameters from existing data supplemented with information gathered as part of this study; (2) describe the water resources, based on the data available, and (3) recommend monitoring programs and additional detailed studies that might be needed.

Figure 1.--Coal fields of Utah (modified from Averitt, 1964, fig. 11).

Historical data pertinent to the hydrology of the study area cover variable periods of record. A common base period of the 1931-75 water years[1] was selected for historical records. Data collection during 1975-77 was designed to fill voids where the historical data were not adequate to satisfy the objectives. Temporary data sites were established for direct or indirect measurement of streamflow and measurement of selected water-quality parameters for ground water, streams, and mine discharge. A well inventory was made, and selected wells were monitored for water-level changes. The data collected during 1975-77 together with selected data from the 1931-75 water years are given in a report by Waddell and others (1978).

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[1] A water year designates the calendar year of the period that ended on September 30 and began October 1 of the previous calendar year.

Physiography

The Wasatch Plateau ranges from about 9,000 to 12,000 feet above sea level and is approximately 4,000 to 7,000 feet above the lowlands to the east and west. The Book Cliffs range from about 7,000 to 10,000 feet above sea level and are about 2,000 to 5,000 feet above the lowlands to the south and west. The canyon of the Price River forms a physiographic break between the Wasatch Plateau and the Book Cliffs.

Another physiographic feature within the study area, the San Rafael Swell, is of lesser importance to coal development. The San Rafael Swell is an elliptical, asymetrical structural dome (anticline) with a northeast-southwest trend that begins southeast of Price and extends southwest through the study area (fig. 1).

Geology

The consolidated-rock formations that crop out in the study area are of Pennsylvanian to Tertiary age (fig. 2). The exposed formations include limestone, sandstone, siltstone, shale, conglomerate, and coal.

Figure 2 (caption on next page) near here

The principal coal-producing formations are of Cretaceous age. The Dakota Sandstone is the oldest formation that contains coal, but it is not an important coal-producing zone in the study area. The Dakota crops out around the northern part of the study area.

Figure 2.--General geology of the Wasatch Plateau-Book Cliffs coal-fields area, Utah.

The Mancos Shale overlies the Dakota Sandstone. The most noteworthy member of the Mancos, in terms of coal production and water resources, is the Ferron Sandstone Member. The Ferron crops out in the lowlands several miles from the Wasatch Plateau and Book Cliffs. The Ferron outcrop generally parallels the uplands but is farther removed from the front of the Book Cliffs than from the edge of Wasatch Plateau. In the vicinity of Emery, coal is being mined (underground) in the Ferron, but coal production from the Ferron is small in relation to that from the Blackhawk Formation (Mesaverde Group) in the Wasatch Plateau and the Book Cliffs. Strip mining of coal in the Ferron has been proposed for the area south and southeast of Emery.

The outcrop of the Blue Gate Member of the Mancos Shale generally marks the beginning of the lowlands, and it crops out along streams several miles upstream from the mouths of most canyons. Shales in the Mancos typically have low permeability, are easily erodible, and contain large quantities of soluble salts, including gypsum ($CaSO_4 2H_2O$), mirabilite ($Na_2SO_4 10H_2O$), and thenardite ($NaSO_4$). Ground-water seepage contributes large quantities of dissolved salts to all the streams in the study area where they cross the outcrops of the shales. Most dissolved constituents are contributed to streams where the Blue Gate is widely exposed along the eastern base of the Wasatch Plateau.

The shales also have a profound influence on topography and landscape because of their ease of erodibility, their salts, which limit plant growth, and their low permeability, which causes most of the precipitation to run off directly into streams. The high percentage of runoff, the rapid weathering due to expansion and contraction resulting from seasonal hydration and dehydration of salts, and the softness of the shales stimulates erosion and development of badlands.

The Mesaverde Group overlies the Mancos Shale in the Wastach Plateau and western Book Cliffs. The Blackhawk Formation of the Mesaverde is the most important coal-producing formation in Utah. The Blackhawk is composed of sandstone, shale, and coal, and coal beds as thick as 20 feet are found locally in the lower part of the formation (U.S. Geological Survey, 1964, p. 45).

The North Horn Formation of Tertiary and Cretaceous age and younger formations that overlie the Mesaverde Group are not important coal producers. However, they yield large quantities of freshwater to numerous springs and seeps that flow into streams at the higher altitudes of the Wasatch Plateau and Book Cliffs.

Climate

Precipitation

The average annual precipitation exceeds 40 inches at the higher altitudes of the Wasatch Plateau as compared to a maximum of about 20 inches in the Book Cliffs (fig. 3). The precipitation varies widely across the study area, gen-

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erally reflecting variations in altitude. South of the town of Green River, where the low point of the study area is at about 4,100 feet above sea level, the average annual precipitation is less than 6 inches.

Figure 3.—Average annual precipitation, 1931-75, Wasatch Plateau-Book Cliffs coal-fields area, Utah.

The average annual precipitation in the study area was shown by isohyetal lines by the U.S. Weather Bureau (no date) for 1931-60. The average annual precipitation for 1931-60 and 1931-75 was compared for 10 stations in and near the study area to determine if adjustments to the Weather Bureau isohyetals would be necessary in order to be representative of 1931-75 averages (table 1). The comparison indicated that precipitation at the 10 stations was, on

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the average, about 3 percent greater during 1931-75 than during 1931-60. The small increase showed no pattern of consistency; therefore, the 1931-60 isohyetals were accepted as representative of 1931-75 and are shown in figure 3.

The annual distribution of precipitation in the study area during 1931-75 is shown in figure 4 for a representative site--Scofield Dam. The U.S. Weather

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Figure 4 (caption on p. 22) near here

Bureau precipitation record for Scofield Dam begins in 1951, but the record was extended back to 1931 by correlation with the records at three other sites in and near the study area.

According to figure 4, the annual precipitation at Scofield Dam during 1931-75 ranged from 6.77 to 32.03 inches and averaged 16.0 inches. Figure 3, however, indicates that the average annual precipitation at Scofield Dam is about 23 inches. The difference may be due to a combination of several factors--difference in base periods, errors of estimates by correlation, location of gage relative to mountain ranges, and local interference.

Table 1.--Comparison of average annual precipitation for 1931-60 and 1931-75 for selected sites in Utah in and near the study area (sites shown in fig. 2)

Site	1931-1960 (A)	1931-1975 (B)	Ratio B/A
Emery	7.23	7.14	0.99
Hanskville[1]	5.07	5.25	1.04
Hiawatha	12.89	12.94	1.00
Manti[1]	11.94	12.29	1.03
Moab 4NW[1]	8.19	8.21	1.00
Moroni[1]	9.46	9.44	1.00
Myton[1]	6.39	7.10	1.11
Salina[1]	9.39	9.73	1.04
Spanish Fork Power House[1]	16.75	17.75	1.06
Thompson	8.56	8.46	.99

[1]Outside of study area.

Figure 4.--Annual precipitation and lake evaporation at Scofield Dam, 1931-75.

The seasonal distribution of precipitation at Scofield Dam for the 1931-75 is shown in figure 5. The monthly precipitation ranged from 6 percent of

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Figure 5 (caption on next page) near here.

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of the annual average in May, June, and November to 12 percent in January.

Evaporation

The evaporation at Scofield Dam for 1931-75 is shown in figure 4. The U.S. Weather Bureau evaporation record for Scofield Dam, which is at an altitude of 7,630 feet, begins in 1947; but the record was extended back to 1931 by correlation with the record of Utah Lake at Lehi. The evaporation at Scofield Dam ranged from 27 to 44 inches per year and averaged about 35 inches during the 1931-75 water years. The average annual evaporation at lower altitudes in the study area, where temperatures are higher, would be greater. For example, at Green River, Utah, which is at an altitude of 4,120 feet, the average annual evaporation was about 42 inches for the 1931-75 water years.

The seasonal distribution of evaporation at Scofield Dam for 1931-75 is shown in figure 5. The monthly evaporation ranged from 1 percent of the average annual in December, January, and February to 17 percent in July.

Air temperature

The average air temperature in the study area ranges from about 35°F at Soldier Summit, which is representative of the higher altitudes of the Wasatch Plateau, to more than 50°F at Thompson in the lowlands to the east. Daily temperatures at Price are shown in figure 12. Although the extremes of daily temperature vary throughout the basin, the thermograph for Price is typical of seasonal fluctuations.

Figure 5.--Monthly distribution of precipitation and evaporation at Scofield Dam, 1931-75.

Surface water

The five major streams whose headwaters originate in the Wasatch Plateau are the Price River and Cottonwood, Ferron, Huntington, and Muddy Creeks. These streams form the headwaters of three drainage basins--the Price River basin (Price River), the San Rafael River basin (Cottonwood, Ferron, and Huntington Creeks), and the Dirty Devil River basin (Muddy Creek). The Price and San Rafael Rivers drain into the Green River, whereas the Dirty Devil River drains into the Colorado River below the mouth of the Green River. (See fig. 1.) The main stem of the Green River cuts through the Book Cliffs in the south-central part of the study area.

The flow in streams that head in the Book Cliffs is extremely small in comparison to the flow of the major streams in the Wasatch Plateau. Most of the streams that drain the Book Cliffs east of the Green River flow into the Colorado River. Many of the streams that head in the Book Cliffs are perennial at higher altitudes, but they become ephemeral as they emerge from the mountains and flow out onto the lowlands.

Stream-data numbering systems

The Geological Survey uses a nationwide system of numbering sites on streams by referring to the position of the site or station in a downstream order in a given major river basin. The study area is in Part 9, the Colorado River Basin.

Gaging-station numbers are assigned in a downstream direction along the main stems of the major streams, and all stations on a tributary stream that enters above a main-stem station are numbered before that station. A similar order is followed in listing stations on first rank, second rank, and other ranks of tributaries. The numbering system consists of an 8-digit number for each station, for example 09327450. The first two digits (09) represent the "part" number identifying the hydrologic region used by the Geological Survey for reporting surface hydrologic data. The next six digits represent the position of the location in a downstream order.

For sites on streams where miscellaneous measurements of discharge or chemical quality or other measurements or samples are taken the station is numbered by using simple reference numbers. The reference numbers are shown on the maps by the appropriate site location symbol.

Streamflow

Average discharge

Average discharges were computed from gaging station records, estimated from channel-geometry measurements, or estimated from discharge-drainage area relationships. Records of streamflow at 49 stations in the study area are available for the 1931-75 water years (table 2). A few pre-1931 records are available, but most of the streamflow data has been gathered since 1931. Although the gaged sites in the Wasatch Plateau have variable lengths of rec-

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Table 2 (next page) near here

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ord, the average annual flows of the major streams were adjusted to the common base period of 1931-75 water years through correlation with stations having records for the missing periods.

Approximately 50-70 percent of the streamflow occurs during May-July (fig. 6). This results from the melting of snow that fell during October-

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Figure 6 (caption on p. 29) near here

April, particularly above altitudes of 6,000 feet.

Figure 6.--Discharge of Price River and Cottonwood, Ferron, and Muddy Creeks above and below diversions for selected water years. (See table 2 for names of gaging stations.)

The annual variability of flow in Huntington Creek for the 1931-73 water years is shown in figure 7. The annual flow ranged from about 25,000 to

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Figure 7 (caption on next page) near here

150,000 acre-feet and averaged 65,000 acre-feet per year. The annual flows of Huntington Creek correlated well with flows of other major streams in the Wasatch Plateau; the Huntington Creek record, therefore, was used to extend the average annual flows of streams having shorter periods of record.

The average annual discharges of ephemeral streams (primarily in the Book Cliffs) were estimated from channel-geometry measurements using a technique described by Fields (1975). These discharges were then correlated with drainage areas, and other estimates of discharge were made at additional sites on the basis of comparison of drainage areas. Table 3 is a summary of estimated

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Table 3 (p. 32) near here

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discharges and drainage areas of miscellaneous sites on perennial and ephemeral streams. The average discharges for only the larger streams are depicted in figure 8.

Figure 8 (caption on next page) near here

Figure 7.--Annual discharge of Huntington Creek, 1931-73.

Figure 8.--Average discharges of streams, Wasatch Plateau-Book Cliffs coal-fields area, Utah.

Table 3.--Estimated average annual discharge and drainage area at miscellaneous sites on ephemeral and perennial streams

Site number: See explanation of numbering system in text and figure 8 for location of data sites.
Estimated average annual discharge: From channel-geometry measurements.

Site number	Ephemeral (E) or perennial (P)	Estimated average annual discharge (acre-feet per year)	Drainage area (square miles)
09163510	E	700	18.2
09163527	E	900	18.1
09163560	P	5,900	158
09163570	E	2,200	26
09163610	E	1,000	89.6
09163715	P	1,700	48.2
09163717	E	1,700	25.5
09163719	E	800	26.3
09312800	P	6,700	62
09312901	P	7,100	80.6
09313021	E	100	4.5
09313025	E	150	3.9
09313027	E	180	8.4
09313041	P	1,600	23.1
09313301	E	70	1.4
09313303	E	90	1.2
09313306	P	90	.62
09313307	P	400	.98
09313308	P	100	.26
09313565	P	14,000	90.1
09313813	E	70	2.6
09313815	E	70	1.6
09313817	E	230	4.8
09313851	E	90	3.6
09313853	E	80	.63
09313855	E	140	4.2
09313964	P	7,200	22.4
09313965	P	9,300	27.9
09313966	E	90	1.3
09313972	P	5,900	11.3
09313973	P	940	3.6
09313976	P	5,600	23.4
09314320	P	2,500	39.9
09314362	E	390	69.3
09314367	P	1,100	5.6
09314368	E	460	43.9
09314369	E	560	113
09314374	P	3,600	13.3
09314701	E	2,900	83.3
09315005	E	940	76.5
09328850	E	1,200	30.1
09328900	E	940	23
09331827	P	3,800	85.4

Diversions

Most of the water from the major streams is diverted for irrigation. Figure 6 shows the net change of flow during selected water years resulting primarily from diversions from the Price River and Cottonwood, Ferron, and Muddy Creeks.

Effects of mining

Mining may change the distribution of water along a stream. The flow of streams along a particular reach may change, depending upon the relation of tunneling and resulting subsidence to aquifers that are hydraulically connected to the stream. In order to determine whether mining is affecting streamflow, measurements are required to define the seasonal and annual variability of the streamflow above and below mining areas.

Sufficient current (1977) data are not available for direct definition of seasonal and annual variabilities of streamflow in all areas that may be affected by mining. Many years of streamflow records would be required at a site in order to provide adequate definition of variation of flow. However, correlation of existing long-term streamflow records with short-term records can aid in obtaining a more accurate estimate of streamflow for a given site.

An example of such a correlation follows. Gaging stations on Huntington (site 09318000), Ferron (site 09316500), Cottonwood (site 09324500) and Muddy (site 09330500) Creeks, have been operated for a number of years above diversions near the canyon mouths. Low flows during August-November at the station on Huntington Creek correlate well with streamflow at the other three sites. The best correlation exists for September flows, the standard error of estimate ranging from about 15 to 25 percent of the mean (table 5 and fig. 9).

Table 5 (p. 36 of ms) near here

Figure 9 (caption p. 37) near here

Correlation between the Huntington and Ferron Creek stations based on varying lengths of record (fig. 10) also indicate that low-flow records for

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Figure 10 (caption p. 37) near here

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a 3-year period would allow estimates within about 20 percent of the mean for September flows. These estimates were made using a 15-year sample of observed flows for Huntington and Ferron Creeks and testing all combinations of possible September flows. Thus, if a tributary that might be affected by mining in the Wasatch Plateau were gaged during September for 3 years, while the main-stem stream was also being gaged, the future record of the tributary could be estimated within about 20 percent of the mean of the main-stem record. Ten years of record would reduce the standard error to only about 16-17 percent, and 15 years to about 15 percent. Incorporation of other streamflow characteristics and climatic parameters, such as the distribution of precipitation, might improve the low-flow relationship, especially for smaller drainage basins.

Figure 9.--Relation of September flows at Huntington Creek to sites on Cottonwood, Ferron, and Muddy Creeks.

Figure 10.--Relation of the standard error of estimate of low-flow correlations to varying years of record. Correlations are between September flows on Huntington Creek (09318000) and Ferron Creek (09316500).

Reservoirs and lakes

The study area contains 53 reservoirs and lakes with a capacity exceeding 100 acre-feet, all except one being in the Wasatch Plateau. In addition, numerous smaller stock ponds are scattered throughout the area. The locations of the 53 reservoirs and lakes are shown in figure 1, and the capacities for the four largest are listed below. The storage capacities of even the largest reservoirs are small in relation to the average annual flow of the streams concerned.

Name	Drainage	Total capacity (acre-ft)	Usable storage (acre-ft)
Scofield Reservoir	Price River	73,780	65,780
Joes Valley Reservoir	Cottonwood Creek	62,460	54,670
Electric Lake	Huntington Creek	31,272	30,528
Mill Site	Ferron Creek	19,200	16,700

Quality of surface water

Temperature

Water temperature has a direct influence on the use of water for domestic supply, fish and wildlife, assimilation of wastes, industry, and agriculture. Temperature influences almost every process that takes place in water, including most chemical reactions and all biological organisms in the aquatic community (Stevens and others, 1975).

The primary controlling factor that influences stream temperature in most areas is generally the climate, particularly the air temperature. Other influencing factors are shading, ground-water inflow, reservoir storage and release, stream orientation, diversions, and effluents from industrial and other uses.

Figure 11 shows the estimated ranges of stream temperature in the study

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Figure 11 (caption on next page) near here

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area. The temperature ranges were compiled from data collected primarily at water-quality sampling sites and gaging sites. Temperature data collected during 1944-70 were reported by Whitaker (1970, 1971).

The minimum temperature of all stream water in the study area is the freezing point of freshwater--0°C. The maximum temperature ranges from about 18°C at the higher altitudes of the Wasatch Plateau to 30°C in the lowlands. Water in most of the streams within the mountainous areas drops to 0°C during October and November, whereas in the lowlands it may be December or January before 0°C is reached.

Figure 11.--Estimated range of stream temperature, Wasatch Plateau-Book Cliffs coal-fields area, Utah.

Most of the changes in stream temperature shown in figure 11 are related to the climatic transgression that typically affects streams as they emerge from the Wasatch Plateau and enter the lowland areas.

By relating miscellaneous water-temperature measurements to mean air temperature, thermographs were generated for sites 09318000 and 09318450 on Huntington Creek (fig. 12). This method can be used to generate seasonal

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Figure 12 (caption on next page) near here

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water thermographs for any stream site where miscellaneous water temperatures and concurrent air temperatures have been collected. Site 09318000 is just downstream from a coal-fired powerplant and about 3 miles upstream from the mouth of Huntington Canyon. Site 09318450 is about 20 miles downstream from the canyon mouth and below all major diversions. The estimated thermographs are similar, but the temperatures at the downstream site are about 5° to 10°C higher during the spring and summer.

Figure 12.--Daily air temperature at Price and observed and estimated water temperatures at two sites on Huntington Creek.

Selected chemical and biological parameters

Samples for chemical and biological analyses were collected at 16 stream sites at approximately bimonthly intervals during 1975-76. (See table 6.)

Table 6 (p. 45-46) near here

Additional data were collected at many other sites once or twice during the study. A comprehensive tabulation of water-quality data collected during and prior to 1975-77 is given in Waddell and others (1978). Most of the pre-1975 data include only inorganic chemical parameters.

During 1975-76 emphasis was concentrated on the major streams where the greatest water-quality degradation was suspected. Sites were selected to bracket reaches where water-quality change was most likely to occur. Samples were collected during 1- or 2-day periods on each stream to define changes that occurred in a given reach.

Most water-quality degradation occurred along the mountain fronts where water diversion, waste disposal, consumptive use, and geologic environment all had a pronounced effect. This is demonstrated in figure 13, using dissolved-solids concentration as an index of water quality from the standpoint of dissolved inorganic constituents.

Figure 13 is based on data in Waddell and others (1978), Mundorff (1972), and unpublished data collected by the U.S. Bureau of Reclamation. About 4,000 chemical analyses from 170 sites and over 25 years of daily water-quality records for site 09314500 on the Price River were used in the preparation of figure 13.

Figure 13 (caption on next page) near here

Figure 13.--Concentrations of dissolved solids in surface water, Wasatch Plateau-Book Cliffs coal-fields area, Utah.

The lowest dissolved-solids concentrations are at the higher altitudes; the concentrations increase markedly as the streams emerge from the mountains. The lowest concentrations generally occur during high flows resulting from snowmelt, whereas, the highest concentrations generally occur during the late summer, fall, and winter months when the streamflow is maintained primarily by ground-water seepage. The smallest seasonal changes occur at higher altitudes, and the largest changes occur in the lowlands.

In most streams, at the higher altitudes in the Wasatch Plateau, the minimum concentration of dissolved solids is less than 100 mg/L, and the maximum concentration is less than 250 mg/L. At the higher altitudes, the rocks consist primarily of limestone or other rocks that contain only small amounts of readily soluble materials. The ratio of dissolved calcium to dissolved magnesium (both in milliequivalents per liter) in water draining those rocks generally ranges from 1:1 to 3:1, and the combined concentration of calcium and magnesium approximates that of bicarbonate.

At lower altitudes below diversions, the water changes to a sodium sulfate type and the dissolved-solids concentrations increase, ranging from about 250 to more than 6,000 mg/L. These changes to a large extent are caused by drainage from areas underlain by the Mancos Shale, which contains large amounts of soluble materials. The marked increase of dissolved-solids concentrations below diversions is accentuated by irrigation of relatively impermeable, moderately to highly saline soils developed on the Mancos. (See fig. 2.) Evapotranspiration concentrates salts in the soils or as efflorescences on the soil surface. These salts are dissolved by water seeping through the soils or by surface runoff. Some of this water eventually seeps or flows back into the streams or into ditches that empty into the streams, resulting in increased concentrations of dissolved solids.

Price River

The most upstream site on the Price River that was sampled in 1975-76 was site 09312780 which is above most diversions and populated areas (fig. 8). The most downstream site was 09314250, which is below most diversions and populated areas that have potential to provide pollutant inflows. During each sampling run the concentrations of dissolved-solids increased downstream; the overall increase ranged from 700 to almost 1,200 percent (table 6).

Organic nitrogen, which includes all dissolved nitrogenous organic compounds, is sometimes a good indicator of pollutant inflows such as fertilizer, sewage, barnyard seepage, and effluent from some industrial processes. The concentrations of organic nitrogen generally increased downstream; the largest increase usually occurred between site 09313950 at Wellington and site 09314250 below Miller Creek. The maximum observed concentration, however, was only 1.90 mg/L, which is below the recommended maximum limits of the Environmental Protection Agency (1976, p. 5). Total Kjeldahl nitrogen which represents the total nitrogenous content of dissolved and suspended material in the water also showed a general increase downstream, and a marked change was observed between the two lowermost sites.

Phosphorus, which has its source in rocks, soils, fertilizers, sewage, and industrial effluent, is sometimes an indication of pollution; it is a nutrient that promotes algal growth. Orthophosphate (dissolved phosphorus) increased significantly between the two lowermost sites in the Price River. Dissolved phosphorus was less than 0.02 mg/L at the upper three sites, but it increased to as much as 0.28 mg/L at the lower site. Total phosphorus (suspended plus dissolved) showed a maximum of 0.69 mg/L at the lower site. Phosphorus is not toxic at these concentrations.

Phenols, which may be indicative of pollutive effluents from industrial processes, impart undesirable taste and odor to water supplies, the threshold level is in the range of 0.01-0.1 μg/L. A concentration of 5.0 μg/L is considered harmful to many species of fish (U.S. Federal Water Pollution Control Administration, 1968). Phenol concentrations ranged from 0 to 5 μg/L, with the maximum of 5 μg/L occurring at site 09313550 near Spring Glen. Water discharging at a rate of approximately 10-20 gal/min was observed flowing into the Price River from Hardscrabble Canyon, just north of Spring Glen. About 15-20 percent (by weight) of the total water discharge was finely ground coal. It is not known if phenolic wastes were associated with this effluent, but it was the only visible source of surface inflow immediately upstream from site 09313550.

Dissolved organic carbon (DOC) may be indicative of waste effluent from industrial and agricultural processes. DOC is not specific for any organic compound, but when found in concentrations exceeding about 4 μg/L, more exhaustive tests to pinpoint a specific organic pollutant may be warranted. The maximum concentration of DOC observed was 14.0 μg/L at site 09314250. The maximum concentration occurred at this site during all but one of the sampling runs.

Bacteriological analyses were made for fecal coliform and fecal streptococci bacteria, both of which are indications of water contamination. Fecal coliform bacteria may indicate recent and possibly dangerous contamination as they are found in the gut or feces of warm-blooded animals. The normal habitat of fecal streptococci bacteria is in the intestine of man (Slack and others, 1973, p. 59).

The ratio of fecal coliform to fecal streptococci bacteria (Fc/Fs) can be used as an indication of the origin of bacterial wastes (Millipore Corp., 1973, p. 38-39). If Fc/Fs is greater than or equal to 4, it is strong evidence that the pollution is derived from human wastes. If Fc/Fs is less than or equal to about 0.7, the pollution probably is derived predominantly from the wastes of warm-blooded animals (including livestock) other than humans. If Fc/Fs is between about 0.7 and 4, it is less definitive of the pollutant origin and may be from mixed sources.

The bacterial counts at the uppermost site (09312780) were generally low. The maximum count was 132 colonies of fecal streptococci bacteria per 100 mL, but counts were 40 colonies per 100 mL or less during the other observations. At the other four sites, no downstream consistency was observed, but high counts were observed at the lower three sites where the maximum fecal streptococci bacteria count was 1,640 colonies per 100 mL, and the maximum fecal coliform bacteria count was 620 colonies per 100 mL. Fc/Fs was generally less than about 0.7 at all sites, suggesting that most of the bacterial pollution is from non-human wastes.

Huntington, Cottonwood, Ferron, and Muddy Creeks

Huntington, Cottonwood, Ferron, and Muddy Creeks were each sampled at an upper site above major diversions and a lower site below diversions and most populated areas. The upper sites are near the canyon mouths, just upstream from where the streams emerge from the Wasatch Plateau. Irrigated lands, which are developed primarily on the Mancos Shale, lie between the upper and lower sites.

The dissolved-solids concentrations during 1975-76 in the four streams at the upper sites ranged from 125 to 375 mg/L and at the lower sites from 1,600 to 4,025 mg/L (table 6). Thus, the overall increase ranged from 500 to 1,000 percent. The dominant ions in the water at the upper sites were generally calcium, magnesium, and bicarbonate, whereas sodium and sulfate become more predominant at the lower sites. The downstream changes were primarily due to the combined effects of (1) diversion of water containing low dissolved-solids concentrations, (2) subsequent irrigation and return drainage from moderate to highly saline soils, (3) ground-water seepage, and (4) inflow of sewage and pollutants from the communities between the upper and lower sites.

In the reaches between the upper and lower sampling sites on the four streams, there was also a pronounced increase in the concentration of most of the organic and biological water-quality parameters that are indicative of pollutants.

Organic forms of nitrogen generally increased from the upper to lower sites on the four streams. The maximum observed concentrations, however, was only 2.0 mg/L of dissolved Kjeldahl nitrogen, and it occurred at the lower site on Cottonwood Creek (09325000).

Dissolved phosphorus was almost nonexistent, as all except one sample had less than 0.02 mg/L at all sampling sites on the four streams.

Concentrations of dissolved organic carbon (DOC) and phenols and bacteria counts indicated significant sources of pollutants at the lower sampling sites, especially on Huntington and Cottonwood Creeks. On Huntington Creek, for example, DOC increased from 1.9 to 6.2 mg/L between sites 09317950 and 09318450 during March 1976 and from 3.2 to 7.6 mg/L during July 1976. During January 1976, phenols increased from 3 to 10 μg/L between the two sites. Fecal streptococci bacteria counts at the upper site were less than 40 colonies per 100 mL, but at the lower site counts were as high as 436 colonies per 100 mL. The sources of the pollutants are probably irrigation return flows and stock that graze within the affected reach--Fc/Fs was generally less than about 0.7.

On Cottonwood Creek, DOC increased from 1.6 to 21 mg/L between sites 09324500 and 09325000 during March 1976 and increased from 2.3 to 14 mg/L between the sites during July 1976. The concentration of phenols increased from 0 to 10 μg/L between the sites during January 1976. Fecal streptococci bacteria counts increased from 2 to 3,000 colonies per 100 mL between the sites during January 1976. Several small inflows were observed discharging into Cottonwood Creek at the community of Castle Dale. Here inflows may contain pollutants that contribute to the water-quality deterioration between the sampling sites. Also, another possible source of pollutant inflow is mine discharge into Grimes Wash, which joins Cottonwood Creek between the two sampling sites.

Biological determinations are not available for the discharge from Grimes Wash, however, and it is not known if the high concentrations of DOC and phenols and the high fecal streptococci bacteria counts at the lower site on Cottonwood Creek are from this source.

On Ferron and Muddy Creeks, bacteria counts at the upper sites (09326500 and 09330500) were generally less than about 50 colonies per 100 mL. However, the counts increased markedly to 760 colonies per 100 mL of fecal streptococci bacteria at the lower site (09327550) on Ferron Creek and to 960 colonies per 100 mL of fecal coliform bacteria at the lower site (09332100) on Muddy Creek. Fc/Fs was generally less than 0.7 at both sites, suggesting that most of the bacterial pollution is originating from non-human wastes. Most of the increase of bacteria in Muddy Creek is attributed to inflow from Ivie Creek, which was sampled at site 09332000 near its confluence with Muddy Creek. Ivie Creek had bacteria counts close to or exceeding those of Muddy Creek at site 09332100 below the confluence, at times when the flow of Ivie Creek represented either all or a large percentage of the flow at the lower sampling site on Muddy Creek.

Grassy Trail Creek

Grassy Trail Creek was sampled at sites 09314320 and 09314340 in Whitmore Canyon, above and below the Sunnyside Mine. The mine, which obtains coal from the Blackhawk Formation, intermittently discharges water into Grassy Trail Creek between the two sites, and mine discharge is often a significant part of the streamflow at the lower site. The dissolved-solids concentration of a mine-discharge sample on July 1, 1976, was about 1,600 mg/L. Such a high dissolved-solids concentration suggests that some of the water may be derived from the Mancos Shale, which intertongues with the Blackhawk in the area.

The discharge from the mine affects the water quality at the lower site on Grassy Trail Creek and probably indirectly affects the ground-water system below the canyon mouth because of stream seepage into alluvium. The dissolved-solids concentration ranged from 250 to 451 mg/L at the upper site and from 1,250 to 2,000 mg/L at the lower site (table 6). Part of the increase in dissolved solids is due to intermittent discharge from the mine. The predominant ions in the water at the upper site in Whitmore Canyon are calcium, magnesium, and bicarbonate, whereas at the lower site sodium, bicarbonate, and sulfate are the predominant ions--typical of Mancos Shale influence.

Dissolved nitrite plus nitrate and the total Kjeldahl nitrogen increased from the upper to lower site, but the maximum total nitrogen was only 1.3 mg/L. Concentrations of phosphorus were small at both sites, with a maximum recorded concentration of orthophosphate of only 0.02 mg/L.

Concentrations of dissolved organic carbon were generally higher at the lower site than at the upper; the concentration ranged from 1.4 to 12 mg/L at the upper site and from 3.0 to 15 mg/L at the lower site. No oil and grease were detected in two samples at the lower site, and the maximum phenol concentration was 4 μg/L at the lower site.

Fecal coliform bacteria counts at both sites were 40 colonies per 100 mL or less, but fecal streptococci bacteria ranged from 4 to 196 colonies per 100 mL at the upper site as compared to a range of 12 to 536 colonies per 100 mL at the lower site. For all concurrent samples at the two sites, an appreciable increase in fecal streptococci bacteria occurred from the upper to the lower sampling site.

Water samples from Whitmore Spring, (D-15-13)lddcSl, and from well (D-15-13)2dad-1, both of which discharge from alluvium near the mouth of Whitmore Canyon, had dissolved-solids concentrations and chemical compositions similar to samples obtàined from Grassy Trail Creek at the lower site. This probably reflects the influence of seepage from Grassy Trail Creek into the alluvium near the canyon mouth.

Benthic invertebrates

Benthic invertebrates are used as an indication of prior water-quality conditions in a stream, whereas most chemical parameters are indicative of water-quality conditions only at the time of sampling. The invertebrates are bottom dwellers; they have a lifespan of months or years; and, in some cases they have only slight mobility, which restricts them to a particular environment. A diversity index is often used as an indication of the variety of taxa and number of individuals per taxon at a sampling site (Slack and others, 1973, p. 24). The higher the index number, the more diverse the groups of taxa, and the more likely water quality has been good for a significant period of time.

A benthic-invertebrate survey was made during the fall of 1976. Although one survey cannot describe seasonal variations, the results showed significant decreases in the diversity of the fauna from upper to lower sites on the Price River and Huntington, Ferron, Muddy, and Grassy Trail Creeks (table 6). These decreases in the diversity indexes are related to increases in temperature, dissolved-solids concentration, and concentration of other water-quality parameters between the upper and lower sites. Cottonwood Creek was an exception, and it is not known why the diversity index did not decrease between the upper and lower site on that Creek. An unusually low diversity index of 0.06 occurred at the lower site on Muddy Creek (09332100). This was probably due to an extent to poor water-quality conditions but, in particular, to the presence of very fine sediment that covers the streambed. An abundance of very fine sediment has been observed in the bed material of Ivie Creek, which discharges into Muddy Creek immediately upstream from the sampling site.

Trace elements

Trace-element analyses were made of samples collected at the 16 stream sites (table 7). Many of the elements shown in table 7 can be in coal wastes;

Table 7 (p. 58) near here

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therefore, the analyses were made to provide background information on trace elements in the study area for the level of coal mining existent in 1975-76.

The concentrations of boron, lithium, and strontium generally increase downstream in amounts proportional to the increase of dissolved solids in the streams. The greatest increases occur after most of the water draining from the mountain block is diverted. This is to be expected, however, because irrigation-return flows, seepage from the Mancos Shale, and local inflow of sewage and other pollutants sustain the base flow of the streams in the lower reaches.

Sediment

Estimated sediment yields for the study area are shown in figure 15, which was adapted from a map prepared by the U.S. Department of Agriculture (1973).

Figure 15 (caption on p. 59) near here)

The estimated sediment yields are based largely on the geology of the study area. The yields range from 0.1 to 3 acre-feet per square mile per year. The lower yields generally are from the higher parts of the Wasatch Plateau and Book Cliffs, where the exposed rock types are predominantly limestone and dolomite; the higher yields generally are from the lowlands, where rock types are predominantly shale and sandstone.

Figure 15.--Estimated sediment yields, Wasatch Plateau-Book Cliffs coal-fields area, Utah.

A large percentage of the total sediment yield occurs during infrequent storms; therefore, no attempt was made during the 1975-77 reconnaissance to determine suspended-sediment yields. Bed-material samples, however, were obtained at many stream sites to provide background information about the size and mineralogic character of existing bed material. The sampling sites are shown in figure 15 and the laboratory analyses are given by Waddell and others (1978, table 13). Similar data were collected from representative rock outcrops in the Wasatch Plateau and Book Cliffs (fig. 15) to provide background information that might aid in future studies. (See Waddell and others, 1978, table 14.)

On most of the major streams, clay minerals constitute less than about 20 percent (by weight) of the bed material. On ephemeral streams, particularly at lowland sites several miles from the mountains, clay minerals often constitute more than 20 percent of the bed material.

Soldier, Grassy Trail, and Dugout Creeks all head in the Book Cliffs and have similar geologic and physiographic settings. Selected reaches of these streams were chosen for more detailed study in order to determine trends of bed-material characteristics. Bed material in the three creeks generally increased in clay-mineral content and decreased in calcite content between upper and lower sampling sites (fig. 16).

Figure 16 (caption on next page) near here

Figure 16.--Mineralogic composition of bed material at sites on selected streams.

Soldier Creek was sampled at four sites, and a major tributary, Pine Canyon Creek, was sampled near its confluence with Soldier Creek. The clay-mineral content of bed material in Soldier Creek above Pine Canyon Creek (site 09313972) was 17 percent, in Pine Canyon Creek at the mouth (site 09313973) it was 8 percent, and below the confluence of the two streams (site 09313974) it was 12 percent. At successive sites downstream from the confluence (09313975 and 09313976), the clay-mineral content increased to 17 and 25 percent.

At the upper site on Soldier Creek (09313972), calcite was 25 percent of the bed material, at the mouth of Pine Canyon (site 09313973) calcite was 51 percent, and below the confluence (site 09313974) calcite was 39 percent. At successive sites downstream (09313975 and 09313976), the calcite dropped to 11 and 13 percent (fig. 16). The general trend of decreasing calcite content and increasing clay-mineral content reflects the geologic transition along the reach where the rock types change from predominantly limestone and dolomite to shale and sandstone.

A similar change in the mineralogic character of the bed material occurred on Grassy Trail Creek and a tributary, Dugout Creek. The clay minerals increased from 17 percent at the upper site on Grassy Trail Creek (09314320), to 25 percent near the canyon mouth (site 09314340), and to 46 percent about 15 miles from the canyon mouth in the lowlands (site 09314362). Dugout Creek was sampled at the canyon mouth in the Book Cliffs (site 09314367) and just above its confluence with Grassy Trail Creek (site 09314368). The clay-mineral content increased from 17 percent at the upper site to 67 percent at the lower site. The calcite content showed an overall decrease downstream at Grassy Trail and Dugout Creeks, but the trend was not as pronounced as at Soldier Creek. The latter drains a larger area underlain by limestone and dolomite above the upper sampling site than do Grassy Trail and Dugout Creeks above their upper sampling sites. Changes along stream reaches affected by future mining activities could be monitored relatively inexpensively by means of particle-size analyses and determinations of bed-material mineralogy.

Mine effluent

Effluents from several mines in the study area directly or indirectly affect the quality of water in the streams. Listed below are selected mines and a comparison of the dissolved-solids concentrations of the mine effluent and of the stream water into which the mines discharge. The average discharges of the mines is not known, but all have been observed discharging more than 100 gal/min. Some discharge continuously and other intermittently.

Unnumbered table (next page) here

Location	Mine	Dissolved-solids concentration in mine effluent (mg/L)	Stream and sampling site	Dissolved-solids concentration in stream above mine[1] (mg/L)
(D-13-7)8dac	Utah No. 2	482	Pleasant Valley Creek (Price River tributary), site 09310691	230
(D-14-14)20dcc	Sunnyside	1,600	Grassy Trail Creek (Price River tributary), site 09314320	255-820
(D-16-8)8dda	King No. 2	671	Cedar Creek (Huntington Creek tributary)	671[2]
(D-17-7)27abb	Wilberg	551	Grimes Wash (Cottonwood Creek tributary), site 09324500	141-666
(D-22-4)12bda	Convulsion Canyon	276	Quitchupah Creek (Muddy Creek tributary), site 09331805	421
(D-22-6)29ddd	Emery (Browning)	5,100	Christiansen Wash (Muddy Creek tributary)	([3])

[1]Ranges are for samples collected during 1975-77; single entries are for samples collected concurrently with samples of mine effluent.

[2]All flow from mine.

[3]No sample collected.

Analyses were made on several of the mine effluents for selected dissolved metals (table 9). The concentrations of arsenic, chromium, lead, mercury, and selenium did not exceed the recommended maximum contaminant levels set by the Environmental Protection Agency (1976, p. 5). Analyses also made for total metals (dissolved plus undissolved) in the outflow from the Utah No. 2 Mine indicated that the concentrations of some of the undissolved (suspended) metals were several times greater than those of the dissolved metals. Dissolved arsenic was 0 μg/L as compared to 11 μg/L total; dissolved iron, 20 μg/L as compared to 2,600 μg/L total; and dissolved lead, 0 μg/L as compared to 100 μg/L total. The dissolved and undissolved concentrations of lithium, zinc, and selenium were about the same. The undissolved metals are relatively harmless as long as physical parameters such as pH and redox potential of the water do not allow the toxic metals, such as arsenic and lead, to dissolve. If the undissolved material eventually migrates into an anaerobic zone, such as may exist in the bottom of reservoirs or lakes, the metals may then dissolve. Thus the undissolved material, although relatively harmless in that state, may pose a future threat if the proper solubility criteria are induced in the water.

Ground water

Ground-water data in the Wasatch Plateau and Book Cliffs consists largely of discharge measurements and water-quality analyses for springflow and mine effluents. In the lowland areas, however, water wells were the source of most subsurface information, including well yields, well logs, water-level measurements, and chemical analyses. In addition, well logs and water-quality information from petroleum tests were used to construct stratigraphic sections of the lowland areas.

Mining and resulting subsidence may cause changes in the flow of springs. In extreme cases, springs may disappear or new ones may appear. Discharge and water-quality measurements were made at 65 selected springs in order to initiate a monitoring record that could be used to determine seasonal and long-term variability of flows and quality. The variability of these factors that are due to climatic changes must be established in order to distinguish changes that might occur because of mining. A summary of the discharge measurements and dissolved-solids concentrations as related to geologic source is included in table 8, and selected water-quality parameters, including trace metals, are included in table 9. Tables 8 and 9 also include data for selected wells and mines in the study area.

Table 8 (p. 67) near here

Table 9 (p. 68-69) near here

Numbering system used for wells, springs, and mines

The system of numbering wells and springs in Utah is based on the cadastral land-survey system of the U.S. Government. The number, in addition to designating the well or spring, describes its position in the land net. By the land-survey system, the State is divided into four quadrants by the Salt Lake base line and meridian, and these quadrants are designated by the uppercase letters A, B, C, and D, indicating the northeast, northwest, southwest, and southeast quadrants, respectively. Numbers designating the township and range (in that order) follow the quadrant letter, and all three are enclosed in parentheses. The number after the parentheses indicates the section, and is followed by three letters indicating the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section--generally 10 acres;[1] the letters A, B, C, and D indicate, respectively, the northeast, northwest, southwest, and southeast quarters of each subdivision. The number after the letters is the serial number of the well or spring within the 10-acre tracts; the letter "S" preceding the serial number denotes a spring. If a well or spring cannot be located within a 10-acre tract, one or two location letters are used and the serial number is omitted. Thus (D-12-7)3BCC-1 designates the first well constructed or visited in the SW1/4SW1/4NW1/4 sec. 3, T. 12 S., R. 7 E. Mine sites where hydrologic data were collected are numbered in the same manner, but three letters are used after the section number and no serial number is used. The numbering system is illustrated in figure 17.

[1]Although the basic land unit, the section, is theoretically 1 mi^2, many sections are irregular. Such sections are subdivided into 10-acre tracts, generally beginning at the southeast corner, and the surplus or shortage is taken up in the tracts along the north and west sides of the section.

Figure 17 (caption on next page) near here.

Figure 17.--Well- and spring-numbering system used in Utah.

Wasatch Plateau and Book Cliffs

Most springs in the Wasatch Plateau and Book Cliffs issue from the Star Point Sandstone or younger formations. The yields of the springs measured during 1975-76 ranged from about 0.2 to 200 gal/min. The dissolved-solids concentration of the spring water was generally less than 1,000 mg/L; thus the water is suitable for most uses. Figure 18 shows the approximate ranges of

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Figure 18 (caption on next page) near here.

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dissolved-solids concentration for ground water in the Wasatch Plateau and Book Cliffs. The figure is based primarily upon water-quality data collected from springs during 1975-76 and may not be representative of water in aquifers at various depths within a designated area.

Samples of water were obtained from two springs discharging from the Star Point Sandstone. The dissolved-solids concentrations were 335 and 391 mg/L, and the principal chemical constituents in both samples were calcium, magnesium, bicarbonate, and sulfate.

The floor of the Wilberg Mine, which is at the base of the Blackhawk Formation, rests on the Star Point Sandstone. Seeps from the floor and the roof of the mine were sampled, and the chemical composition of water from both sources was similar. The concentration of dissolved solids from the floor seepage was 572 mg/L as compared to 551 mg/L from the ceiling seepage, and the principal dissolved chemical constituents were calcium, magnesium, bicarbonate and sulfate in both samples.

Figure 18.--Concentrations of dissolved solids in ground water, Wasatch Plateau-Book Cliffs coal-fields area, Utah.

The Blackhawk Formation produces water in many of the mines, including the Convulsion Canyon, King No. 2, Utah No. 2, and Sunnyside Mines. The mining companies have not kept records of total annual discharge. Discharges of several of the mines were measured during 1975-77; but most of the mines are pumped intermittently, and the measurements are not representative of average annual discharge.

With the exception of the Sunnyside Mine, the water from 12 mines and springs discharging from the Blackhawk Formation had dissolved-solids concentrations ranging from about 60 to 800 mg/L; the principal dissolved constituents were calcium, magnesium, bicarbonate and sulfate. The water from the Sunnyside Mine had a dissolved-solids concentration of about 1,600 mg/L. It is not known why water from the Sunnyside Mine is so highly mineralized, but some of the mine water may be derived from Mancos Shale. In this area of the Book Cliffs, the Mancos commonly intertongues with the Blackhawk, and water in the Mancos is usually highly mineralized.

Samples of water were obtained from three points of discharge from the Castlegate Sandstone. The dissolved-solids concentration ranged from 313 to 806 mg/L, and the principal constituents were calcium and bicarbonate.

In 11 samples of spring water obtained from the Price River Formation, the dissolved-solids concentration ranged from 122 to 792 mg/L. Samples with the lower dissolved-solids concentrations were predominantly calcium, magnesium, and bicarbonate type waters, but the waters containing the higher dissolved-solids concentrations were predominantly sodium and bicarbonate types.

Thirty-eight samples were obtained from springs issuing from the Flagstaff Limestone Member of the Green River Formation of Tertiary age and the underlying North Horn Formation. The dissolved-solids concentrations ranged from 142 to 662 mg/L. The springs issue mainly from limestone, and thus the principal dissolved constituents were calcium, magnesium, and bicarbonate.

Lowland area

Little is known about the amount of water than can be obtained from wells in most of the formations that underlie the lowland area. The approximate range of dissolved-solids concentrations in ground water in the lowlands, however, is indicated in the stratigraphic fence diagram (fig. 19).

Figure 19 (caption on next page) near here

The ranges of dissolved-solids concentrations are based largely on the dominant lithology of the various formations and, where available, on chemical analyses of water obtained from water wells and petroleum tests. All formations are not necessarily water bearing in all areas, and the actual quality of water in any given formation at any given location can be determined only by drilling.

Most of the subsurface water in the lowlands contains more than 2,000 mg/L of dissolved solids, and the water is not suitable for public supply. Much of the water contains less than 35,000 mg/L of dissolved solids, however, and it therefore could be used for selected industrial purposes.

Figure 19.--Stratigraphic units and concentrations of dissolved solids, Wasatch Plateau-Book Cliffs coal-fields area, Utah.

The Ferron Sandstone Member of the Mancos Shale is the shallowest aquifer in the area with water of suitable chemical quality for human consumption and for future development for public supply. The public supply for the city of Emery is obtained from well (D-22-6)4cab-1, developed in the lower part of the Ferron. This well is pumped at rates of 150 to 250 gal/min; the water contains about 790 mg/L of dissolved solids. The Kemmerer Coal Co. drilled well (D-22-6)17abc-1 to the lower part of the Ferron about 1.5 miles south of Emery. The water from this well is similar in chemical quality to the water from the Emery well.

Several test holes were drilled into the upper part of the Ferron Sandstone Member a few miles southeast of Emery by Consolidation Coal Co. These test holes were not constructed so as to hydraulically separate the upper part of the Ferron from other possible overlying water-bearing zones. Water levels in the test holes are typically above the top of the Ferron and within a few feet of the land surface. It is not known whether the water levels in these test holes are representative of the potentiometric surface in the upper part of the Ferron or the water table in the overlying Blue Gate Member of the Mancos Shale.

The Ferron Sandstone Member may lose water by seepage to streams and mines, but the quantities involved are unknown. Approximately 200 to 300 gal/min is discharged from the Emery (Browning) Mine, (D-22-6)29ddd, which is about 4 miles south of Emery. Coal is mined from the upper part of the Ferron, but some of the mine water is believed to be coming from the Blue Gate which overlies the Ferron. The concentration of dissolved solids in water from the Browning Mine was 5,100 mg/L on September 16, 1976.

Three samples from wells (D-22-6)4cab-1, (D-22-6)17abc-1, and (D-22-6)31dab-1, believed to be representative of water in the Ferron Sandstone Member had dissolved-solids concentrations ranging from 652 to 1,230 mg/L; the principal constituents were sodium, sulfate, and bicarbonate. The water in the Ferron, although of marginal chemical quality for public consumption, is probably the best obtainable from aquifers within depths of 2,000 feet along margins of the uplands.

Water levels were monitored in 19 wells in the study area during 1975-77. Hydrographs for six wells in the Ferron Sandstone Member near Emery are shown in figure 20. Water levels in most of these wells declined, probably reflecting below-normal precipitation during 1976-77. Although the length of record available is not adequate to attribute the declines solely to climatic variations, this is suggested by the general decline of water levels observed in many of the eight other observation wells that tap different aquifers in other parts of the study area (fig. 20).

Figure 20 (caption on next page) near here

Water levels are an aid in interpreting ground-water conditions in an area, in constructing potentiometric-surface maps, and in determining changes in aquifer storage in response to climatic variations and manmade withdrawals. Any stress imposed on a ground-water system usually is reflected in ground-water levels. Thus, through monitoring of water levels, one may detect future changes in either recharge or discharge to aquifers. Unfortunately, most of the wells available for monitoring in the study area are completed in only a few aquifers and are concentrated in small areas.

Figure 20.--Hydrographs for selected wells, Wasatch Plateau-Book Cliffs coal-fields area, Utah.

Summary and recommendations

This study was designed to provide an assessment of the hydrology of the Wasatch Plateau-Book Cliffs coal-fields area in Utah. The objectives of the study were to establish data bases for hydrologic parameters, to describe the water resources based on available data, and to recommend monitoring programs and additional detailed studies that might be needed.

The principal coal-producing formations are of Cretaceous age. Coal production is from the Ferron Sandstone Member of the Mancos Shale and the Blackhawk Formation of the Mesaverde Group, which is the most important coal-producing formation in Utah.

Five major streams have headwaters that originate in the Wasatch Plateau. They are the Price River and Cottonwood, Ferron, Huntington, and Muddy Creeks. No major streams originate in the Book Cliffs. During the 1931-75 water years, the minimum discharge for the five major streams ranged from about 12,000 to 26,000 acre-feet per year, and the maximum discharge ranged from 59,000 to 315,000 acre-feet per year. Approximately 50-70 percent of the streamflow occurs during May-July, resulting from melting of snow that fell during October-April. Most of the water from the major streams is diverted for irrigation.

Most water-quality degradation in streams occurred along the flanks of the Wasatch Plateau and Book Cliffs where water diversion, waste disposal, consumptive use, and geologic environment all had a pronounced effect. In most streams at higher altitudes in the Wasatch Plateau, the minimum concentration of dissolved solids is less than 100 mg/L, and the maximum concentration is less than 250 mg/L. At lower altitudes, below diversions, the concentration ranged from about 250 mg/L to more than 6,000 mg/L.

Mining may change the distribution of water along a stream. The flow of streams along a reach may change, depending upon the relation of tunneling and resulting subsidence to aquifers that are hydraulically connected to the stream. In order to determine whether mining is affecting streamflow, measurements are required to determine the seasonal and annual variability of the streamflow above and below mining areas. Correlations indicate that 3 years of low-flow records at stream sites in the Wasatch Plateau would allow the development of relationships with long-term sites that can be used to estimate future low-flow records within a standard error of about 20 percent.

1. The low flow of streams below areas that are being mined or proposed for mining should be continuously monitored. The best period for monitoring low flows is during August-November.
2. Low-flow monitoring sites should be supplemented with seepage studies which extend from below to above the coal-development areas.
3. The flow of selected springs in areas with no mining activity should be monitored in order to determine seasonal and long-term natural variability of flow.
4. Water quality at stream sites below coal-development areas should be monitored for inorganic, organic, and biologic parameters which will aid in the detection of possible water-quality degradation.
5. Bed-material characteristics of stream channels should be monitored above, through, and below potential mining areas. Sampling should extend from the Castlegate Sandstone downstream through the Blackhawk Formation and into the upper members of the Mancos Shale. The frequency of sampling should be keyed to periods of significant runoff. Bed-material analysis should include mineralogic and size analysis.
6. Subsurface information that will aid interpretation of ground-water hydrology should be collected from on-going drilling operations of private companies and other Federal agencies.
7. Comprehensive basin studies should be initiated to enable construction of accurate water budgets and to develop the capability to accurately predict the effects of coal mining on the various components of the hydrologic system.

8. Initiate a study to determine the areal extent of the aquifer in the Ferron Sandstone Member of the Mancos Shale; the potential of the Ferron as a source of water supply; and the effect that proposed strip mining might have on flows of affected streams, the potentiometric surface of the aquifer, and production of existing wells.

9. Monitoring of water levels in wells should be continued, and selected wells should be added to the network as they become available to improve areal distribution of monitoring sites.

10. A subsidence-monitoring program should be initiated under the guidance of State and Federal agencies charged with this responsibility.

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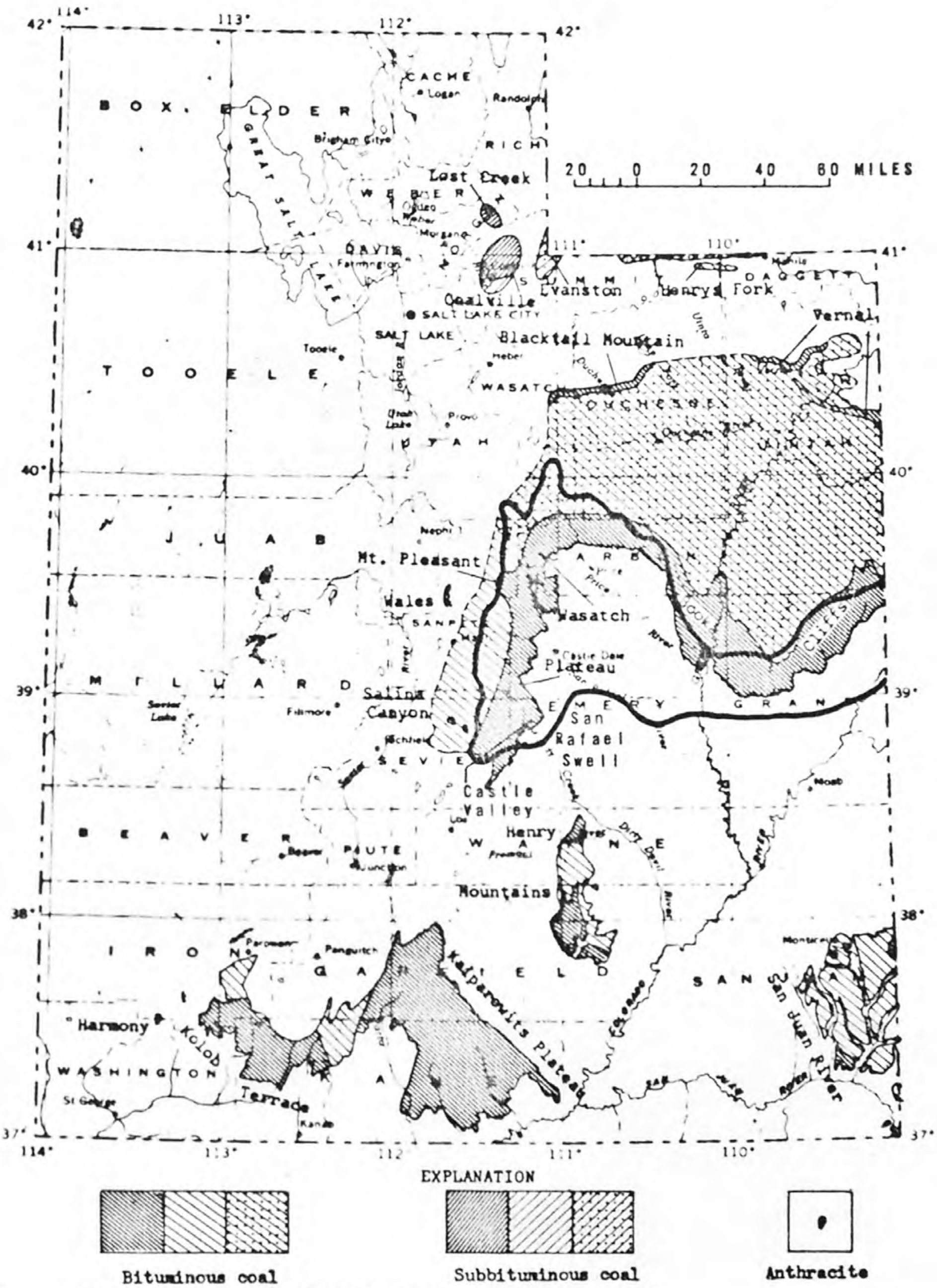

EXPLANATION

Bituminous coal — Subbituminous coal — Anthracite

Dark ruling: Known accessible coal in named coal fields
Light ruling: Thin and discontinuous coal or meager information about the coal
Stippling: Coal-bearing rocks concealed by younger rocks
——— Boundary of study area for this report

Figure 1.— Coal fields of Utah (modified from Averitt, 1964, fig. 11).

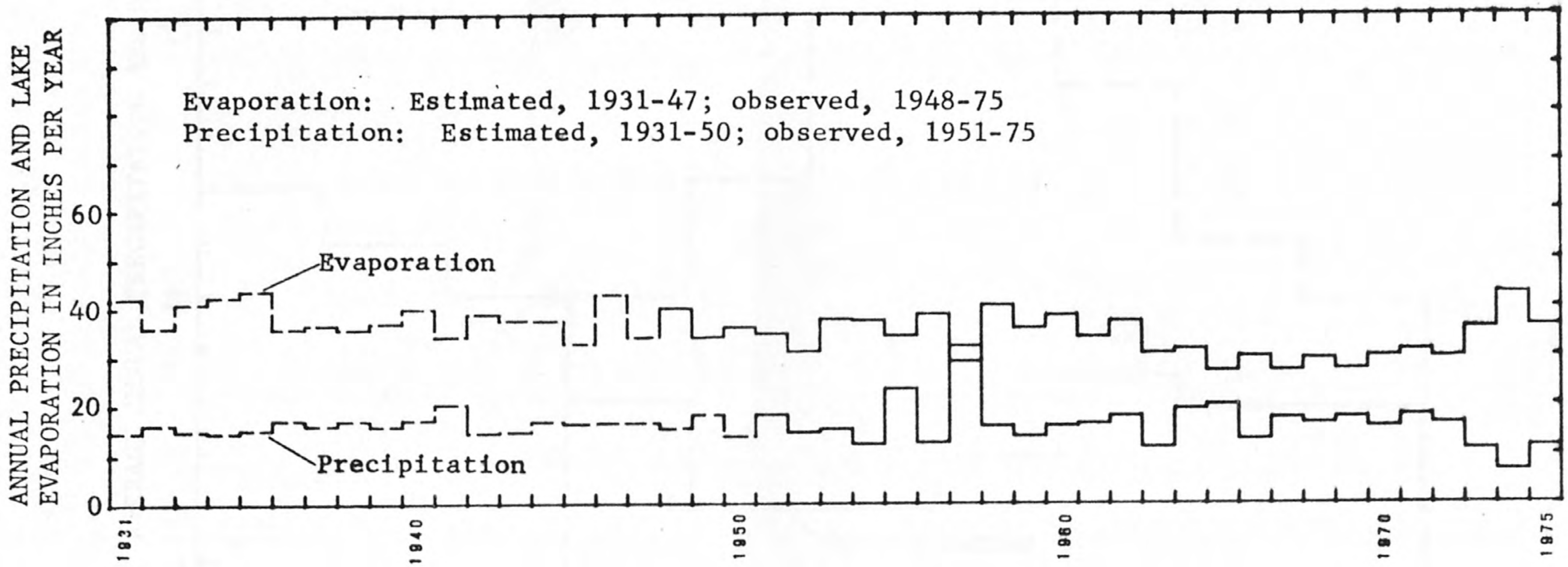

Figure 4.--Annual precipitation and lake evaporation at Scofield Dam, 1931-75.

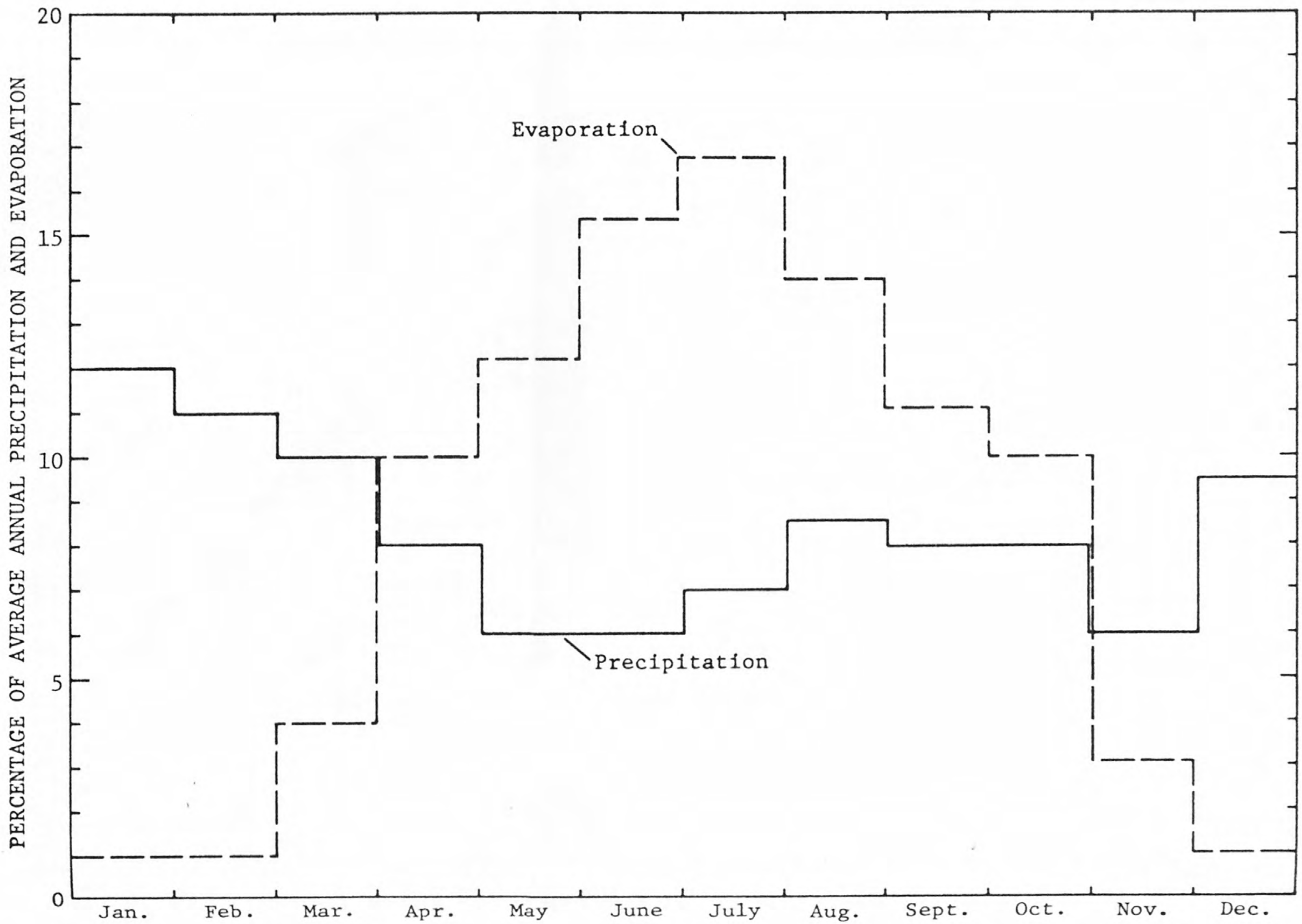

Figure 5.--Monthly distribution of precipitation and evaporation at Scofield Dam, 1931-75.

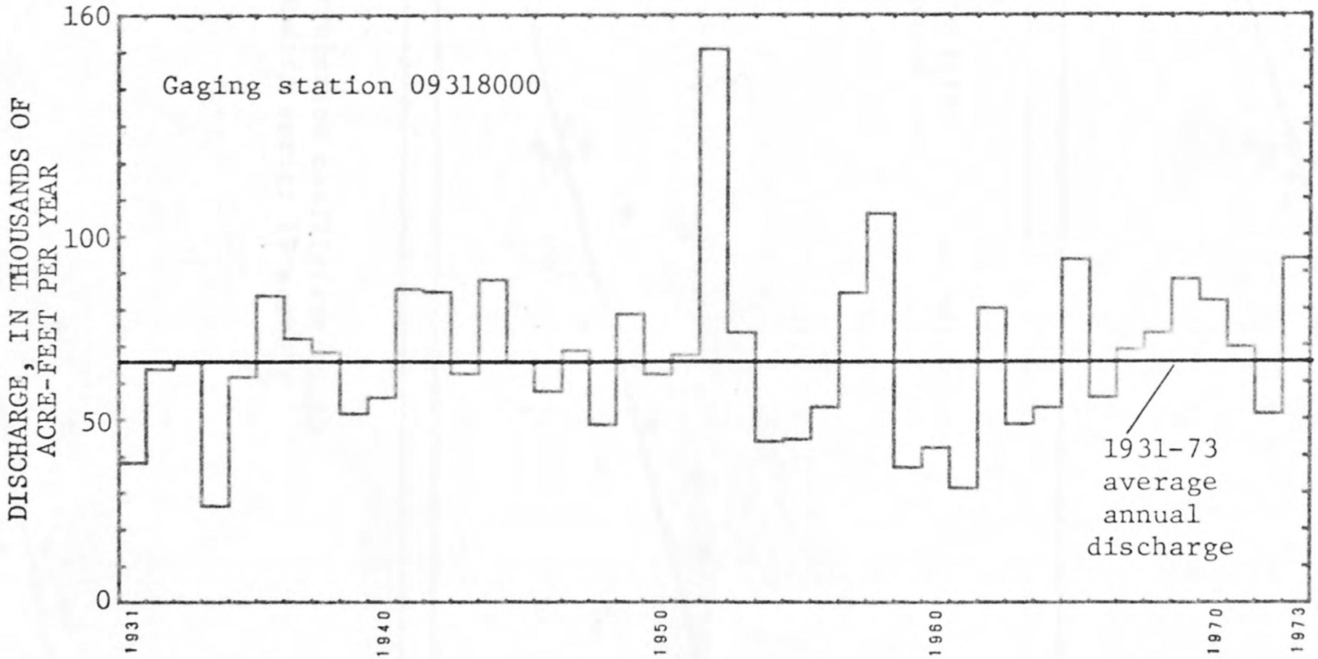

Figure 7.--Annual discharge of Huntington Creek, 1931-73.

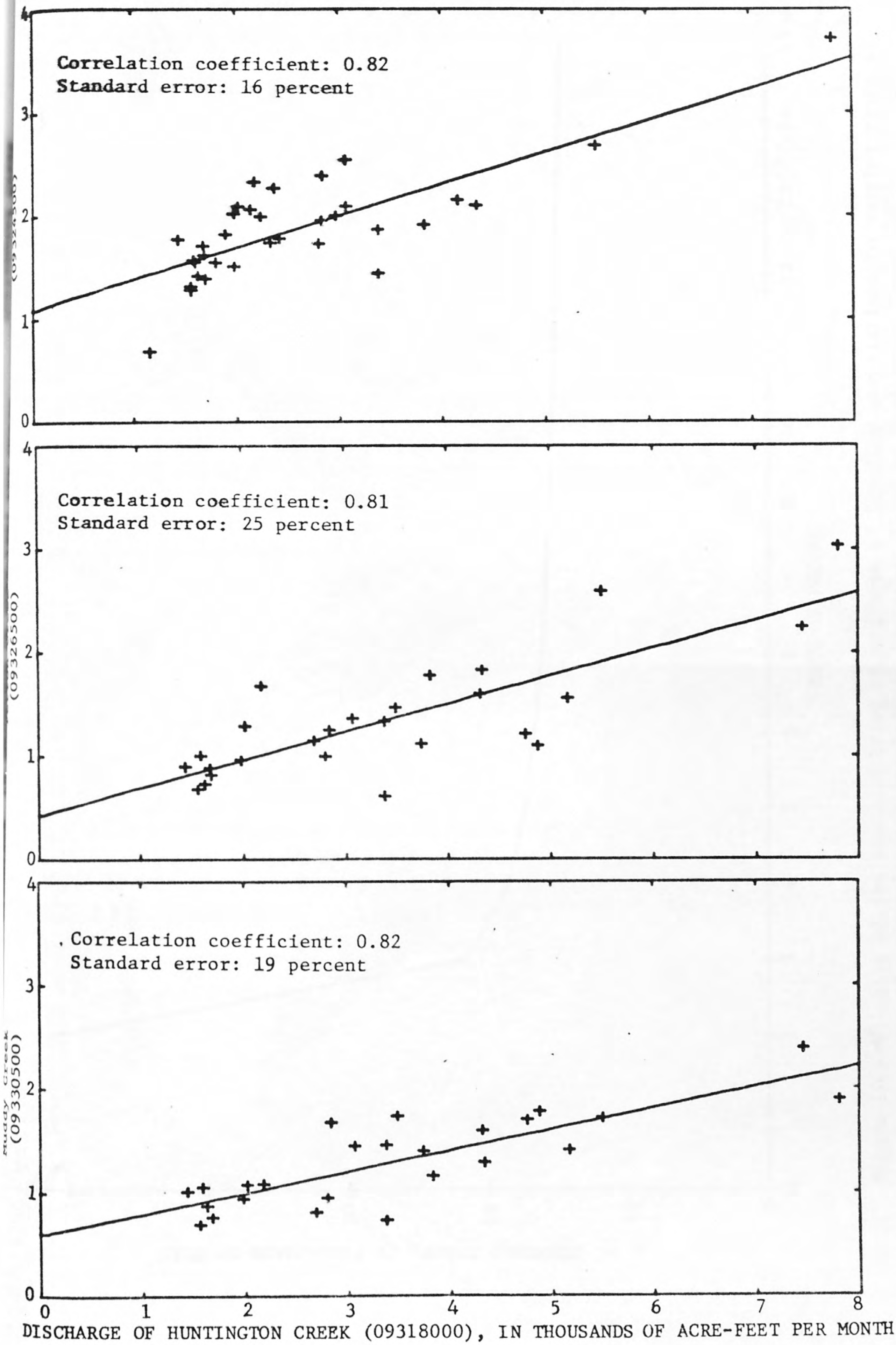

Figure 9.--Relations of September flows at Huntington Creek to sites on Cottonwood, Ferron, and Muddy Creeks.

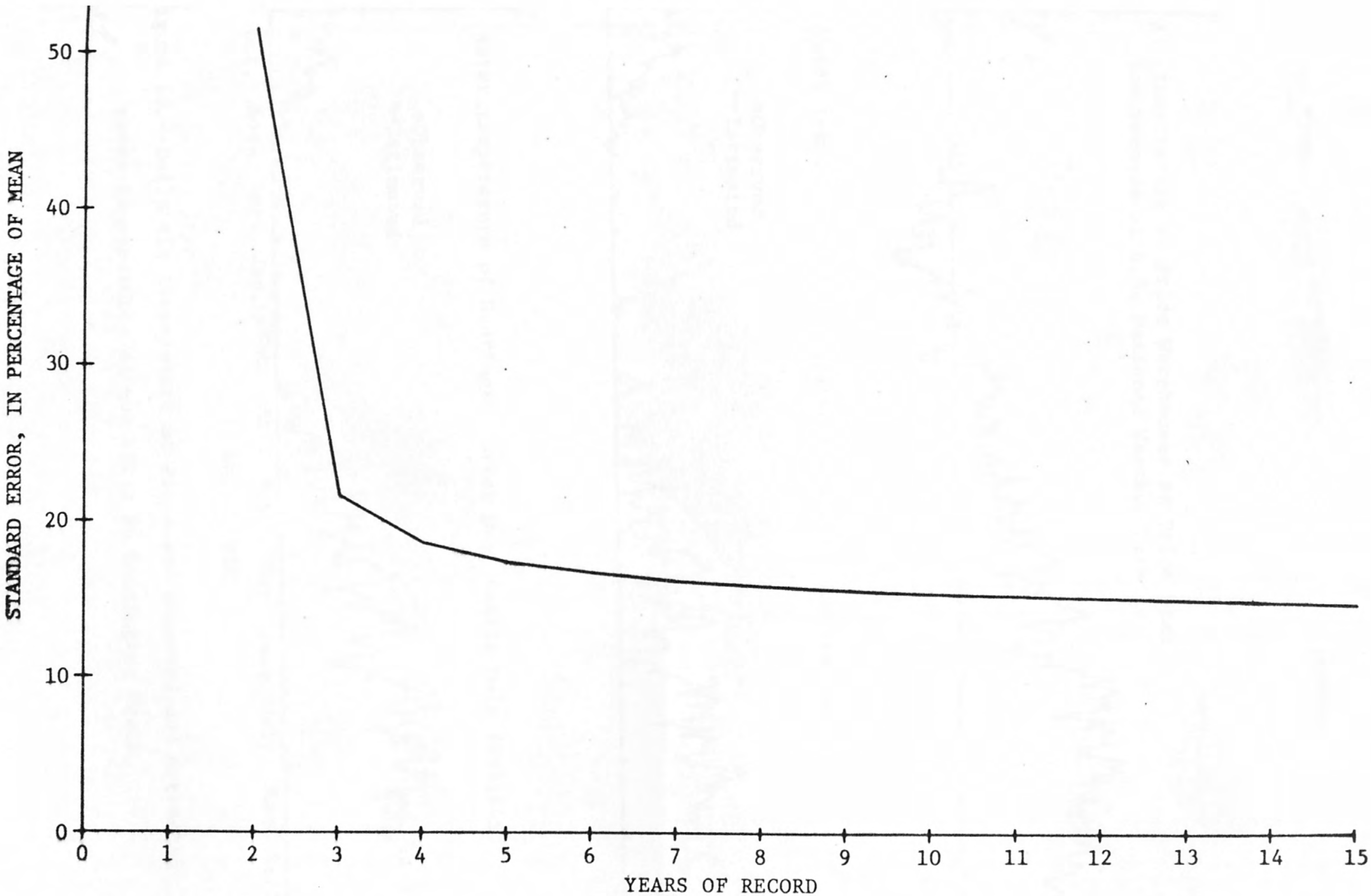

Figure 10.--Relation of the standard error of estimate of low-flow correlations to varying years of record. Correlations are between September flows on Huntington Creek (09319000) and Ferron Creek (09316500).

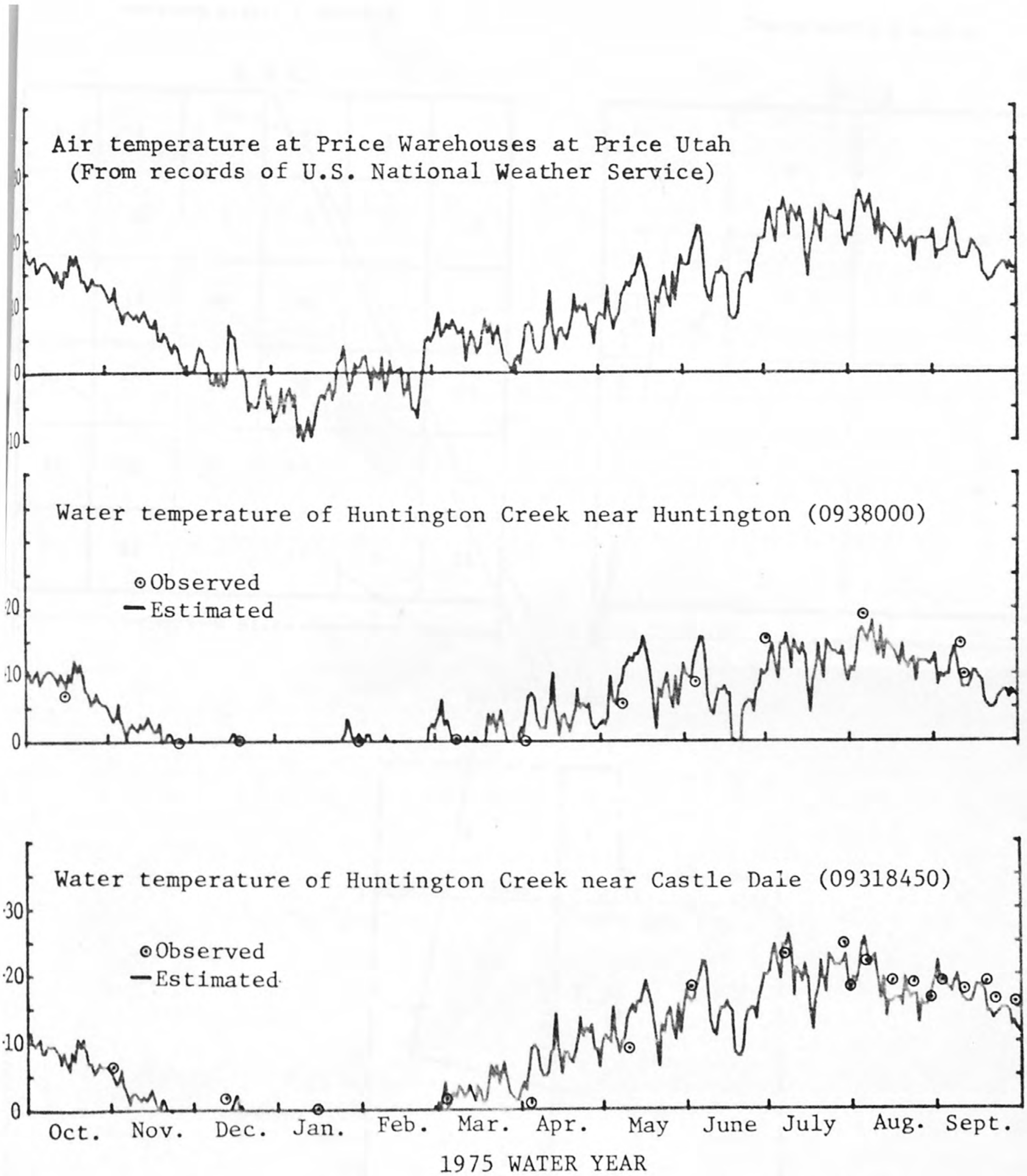

Figure 12.--Daily air temperature at Price and observed and estimated water temperatures at two sites on Huntington Creek.

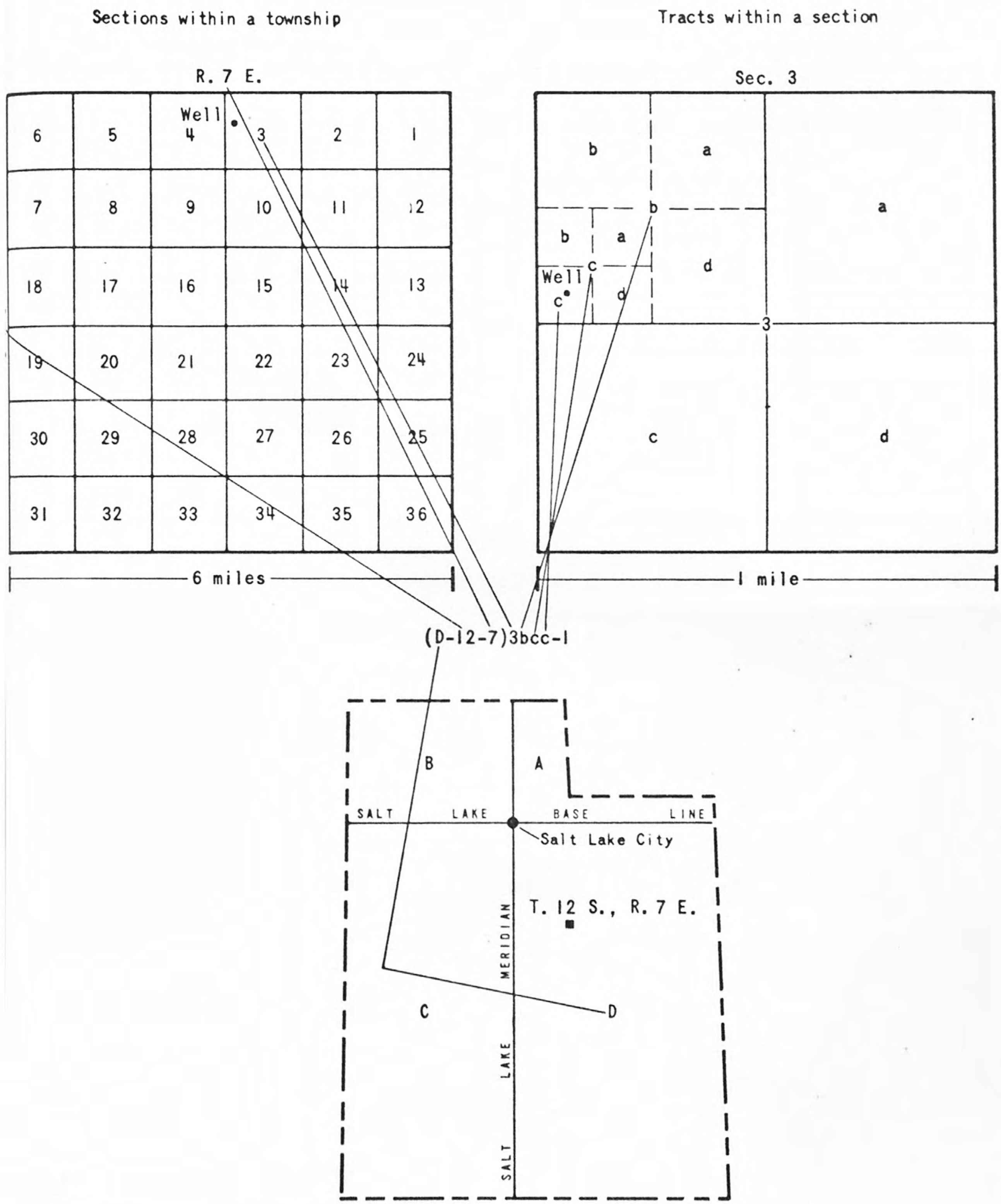

Figure 17.--Well- and spring-numbering system used in Utah.