WATER RESOURCES OF THE COTTONWOOD WASH WATERSHED, UTE MOUNTAIN UTE INDIAN RESERVATION, SOUTHWESTERN COLORADO

By Arthur L. Geldon

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CONVERSION FACTORS

For readers who prefer to use metric (SI) units, conversion factors for terms used in this report are listed below:

Multiply	*By*	*To obtain*
acre	0.4047	hectare
acre-foot (acre-ft)	1.233×10^{-3}	cubic hectometer
acre-foot per year (acre-ft/yr)	1.233×10^{-3}	cubic hectometer per year
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
gallon (gal)	3.785	liter
gallon per day (gal/d)	0.003785	cubic meter per day
gallon per minute (gal/min)	0.06308	liter per second
inch (in.)	2.54	centimeter
mile (mi)	1.609	kilometer
pint	473.1632	milliliter
square mile (mi^2)	2.59	square kilometer

Temperatures can be converted to degrees Fahrenheit (°F) or degrees Celsius (°C) by the following equations:

$$°F=(9/5\times°C)+32;\quad °C=5/9(°F-32).$$

WATER RESOURCES OF THE COTTONWOOD WASH WATERSHED, UTE MOUNTAIN UTE INDIAN RESERVATION, TOWAOC, COLORADO

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ABSTRACT

Spring-fed streams draining Sleeping Ute Mountain are potential water resources in the arid Four Corners region of Colorado. Cottonwood Wash, near Towaoc, Colo., annually receives about 14,600 acre-feet of precipitation over a 16-square-mile watershed. During water year 1982, 86 percent of the precipitation was consumed by evapotranspiration.

Except for snowmelt from April to June and rainfall from occasional storms, all flow in the wash is from springs. The peak snowmelt runoff during the 1982 water year was an estimated 4.5 cubic feet per second. Surface runoff was about 100 acre-feet. Most springs issue from block rubble and talus, but springs also issue from Mancos Shale, colluvium, pediment alluvium, and channel alluvium. Flow is largest during the spring months, when the ground is saturated from snowmelt, and smallest during the early fall, when many springs cease flowing. The cumulative flow from all springs was about 290 acre-feet during the 1982 water year.

Most of the water in the wash upstream from Towaoc is diverted to Cottonwood Reservoir, where it evaporates or seeps into alluvium. Springs issuing from pediment alluvium downstream from the reservoir may result from reservoir leakage. One of these springs supplies about 19 acre-feet of water per year to Towaoc. All springs downstream from Towaoc are distributary. Water from them seeps back into the channel alluvium within short distances.

The younger of two pediment deposits in the area contains about 2,000 to 4,000 acre-feet of water. The quantity of water in storage depends on seasonal and yearly variations in precipitation. Underflow from the watershed into Navajo Wash was about 740 acre-feet of water during the 1982 water year; recharge to bedrock was about 850 acre-feet of water.

Ground water and surface water in the watershed upstream from Towaoc are typically calcium bicarbonate types with less than 600 milligrams per liter of dissolved solids. However, water issuing as springs from alluvium in the watershed downstream from Towaoc and from Mancos Shale and colluvium throughout the area is a calcium sulfate type with about 500 to 1,500 milligrams per liter of dissolved solids. Selenium concentrations greater than 10 micrograms per liter commonly occur in water issuing as springs from the Mancos Shale and from alluvium during the spring months when discharges are relatively large.

Augmentation of municipal supplies could be accomplished by: (1) Development of springs upstream from Towaoc; (2) utilization of water seasonally stored in Cottonwood Reservoir; (3) enlargement of a presently used infiltration gallery; or (4) drilling of wells in pediment alluvium.

INTRODUCTION

The Ute Mountain Ute Indians are having considerable difficulty obtaining water for residents of Towaoc (pronounced toy-uk), the tribal seat. Towaoc, at the base of Sleeping Ute Mountain, is in Montezuma County in the Four Corners region of Colorado (fig. 1). In 1983, most of Towaoc's water supply was diverted from the Dolores River, 22 mi away. A spring near Towaoc augments this supply. Water supplies are barely adequate to support the current population and cannot sustain an influx of residents anticipated by community leaders.

Spring-fed washes draining Sleeping Ute Mountain are a potential water resource for the town. One of these washes, Cottonwood Wash, passes through Towaoc. During 1982 and 1983, the U.S. Geological Survey, in cooperation with the Ute Mountain Ute Indian Tribe, investigated shallow surface water and ground water in the Cottonwood Wash watershed.

Specific objectives of the investigation included: (1) Determination of inflow from precipitation, surface water, and ground water; (2) determination of spring discharge, streamflow, and ground-water storage; (3) determination of the thickness, composition, and yield of alluvium; (4) determination of outflow by evapotranspiration, underflow, recharge to bedrock, surface runoff, and consumptive use; (5) evaluation of the quality of shallow ground water; and (6) assessment of alternatives for water-resource development and their impacts on the hydrologic system. To meet these objectives, a monitoring network of springs, streamflow measurement sites, and wells was established. Data collected at these sites from May 1982 to April 1983 were used in hydrologic interpretations. Data available in water-resources data reports for Colorado, New Mexico, and Utah (U.S. Geological Survey, 1982a, 1982b, and 1982c) and climatological data reports for Colorado, New Mexico, and Utah (National Oceanic and Atmospheric Administration, 1930-82, 1980a, 1980b) were used also.

Previous reports on the area generally are regional in nature. Powell (1954) discussed the results of drilling for an artesian water supply on the Ute Mountain Ute Indian Reservation. Irwin (1966) discussed the hydrology of the reservation. Among others, Hanshaw and Hill (1969), Woodward-Clyde Consultants (1982), Andrews and others (1983), and Whitfield and others (1983) discussed the regional hydrology of the southern Paradox basin, which includes the study area. Reports pertaining to nearby areas include: Harshbarger and Repenning (1954), Davis and others (1963), Kister and Hatchett (1963), Cooley and others (1964, 1966, 1969), McGavock and others (1966), U.S. Soil Conservation Service (1974), Sumsion (1975), Brogden and Giles (1976), Brogden and others (1979), Thackston and others (1981), and Weir and others (1983).

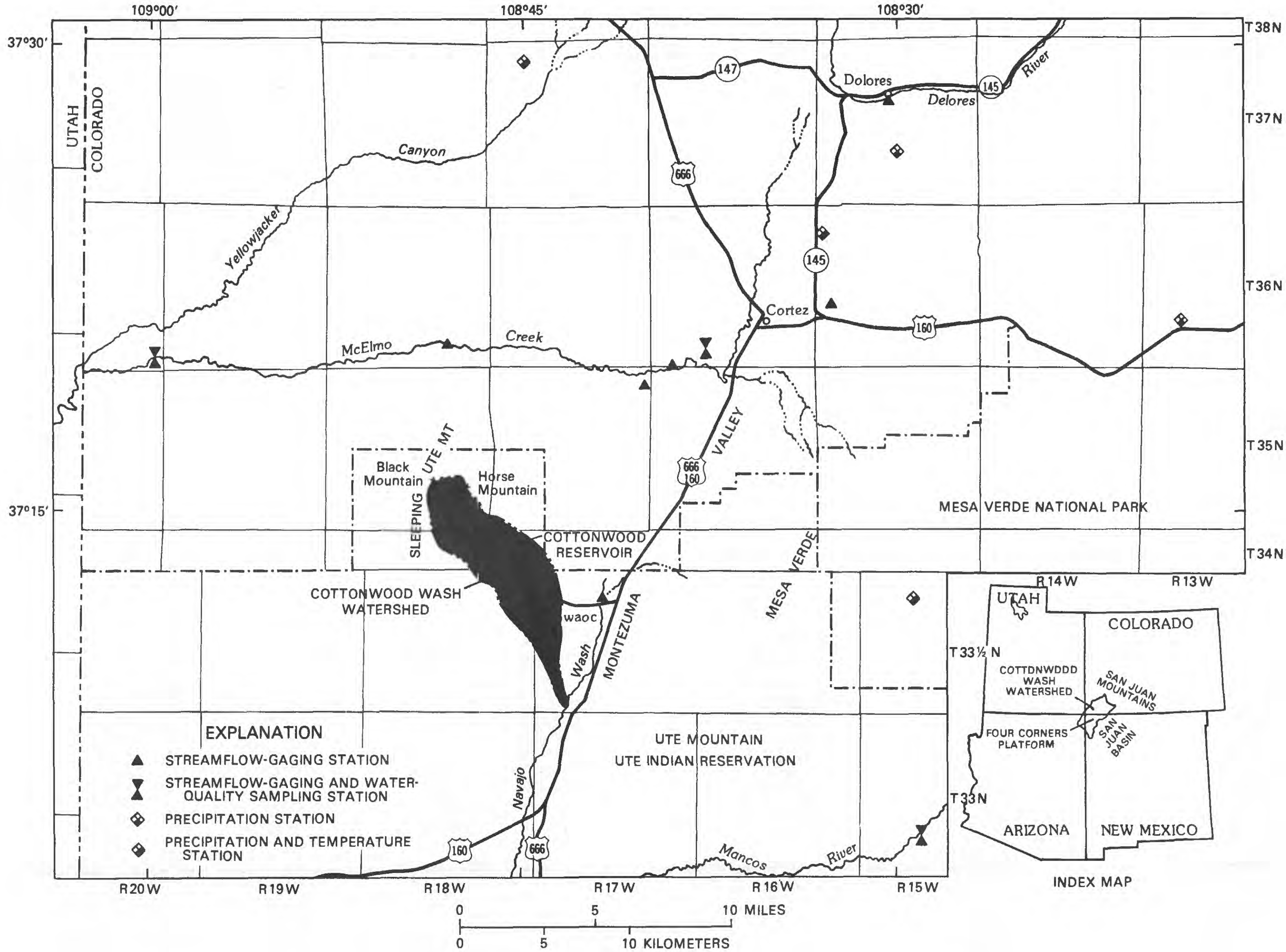


Figure 1.--Location of Cottonwood Wash watershed and nearby data-collection sites.

The author gratefully acknowledges Joseph Keck and other officials of the Ute Mountain Ute Indian Tribe, Kenneth Mullen of the U.S. Bureau of Reclamation, Durango, and personnel of the U.S. Soil Conservation Service, Cortez and Denver, who assisted in obtaining information used in this report. Special commendation is given to William D. Harlan, Linda G. Saindon, and George H. Leavesley, U.S. Geological Survey, who provided guidance in the use of the Precipitation-Runoff Modeling System.

PHYSIOGRAPHIC SETTING

Geography

The Cottonwood Wash watershed (fig. 1) is 16.1 mi^2 in area. Cottonwood Wash is one of several intermittent to ephemeral streams draining the east side of Sleeping Ute Mountain. Altitudes range from 9,414 ft on Black Mountain and 9,180 ft on Horse Mountain to 5,360 ft at the mouth of the wash. The average altitude of the watershed is 6,978 ft.

Towaoc, the only town in the study area, is situated on the lower of two pediment deposits flanking Sleeping Ute Mountain. The population of the town in 1982 was about 1,200 (Joseph Keck, Ute Mountain Ute Indian Tribe, oral commun., 1982). Towaoc, at an altitude of 5,900 ft, occupies about 0.7 mi^2 of surface area. A house and racetrack south of Towaoc are the only other developed areas in the watershed.

Cottonwood Wash drains into Navajo Wash, a tributary of the Mancos River. The Montezuma Valley, which is formed by Navajo Wash and other streams, separates Sleeping Ute Mountain on the west from Mesa Verde on the east. Cortez, the largest town in the valley, had a population of about 8,000 in 1983 (Cortez Chamber of Commerce, oral commun., 1983).

Soils in the Cottonwood Wash watershed reflect the composition of the underlying geologic formations (U.S. Bureau of Indian Affairs, 1966, and U.S. Soil Conservation Service, written commun., 1982). In the lower part of the watershed, the soil is predominantly clay and cobbly gravelly loam; sand and gravel occur within and adjacent to channels of the wash. An area of outcropping Jurassic and Cretaceous sandstone and shale northwest of Towaoc is covered with a thin layer of sandy loam. On Sleeping Ute Mountain, much of the surface is rock, talus, and block rubble, but clayey colluvium covers areas underlain by shale, and eolian loam covers a small area known as the "Sun Dance Ground" (fig. 2).

The vegetation varies from grassland at the mouth of the wash to chaparral woodland and montane forest at the higher altitudes (U.S. Bureau of Indian Affairs, 1966). The distribution pattern depends mostly on topographically controlled variations in precipitation and temperature but is modified by soil type and slope aspect.

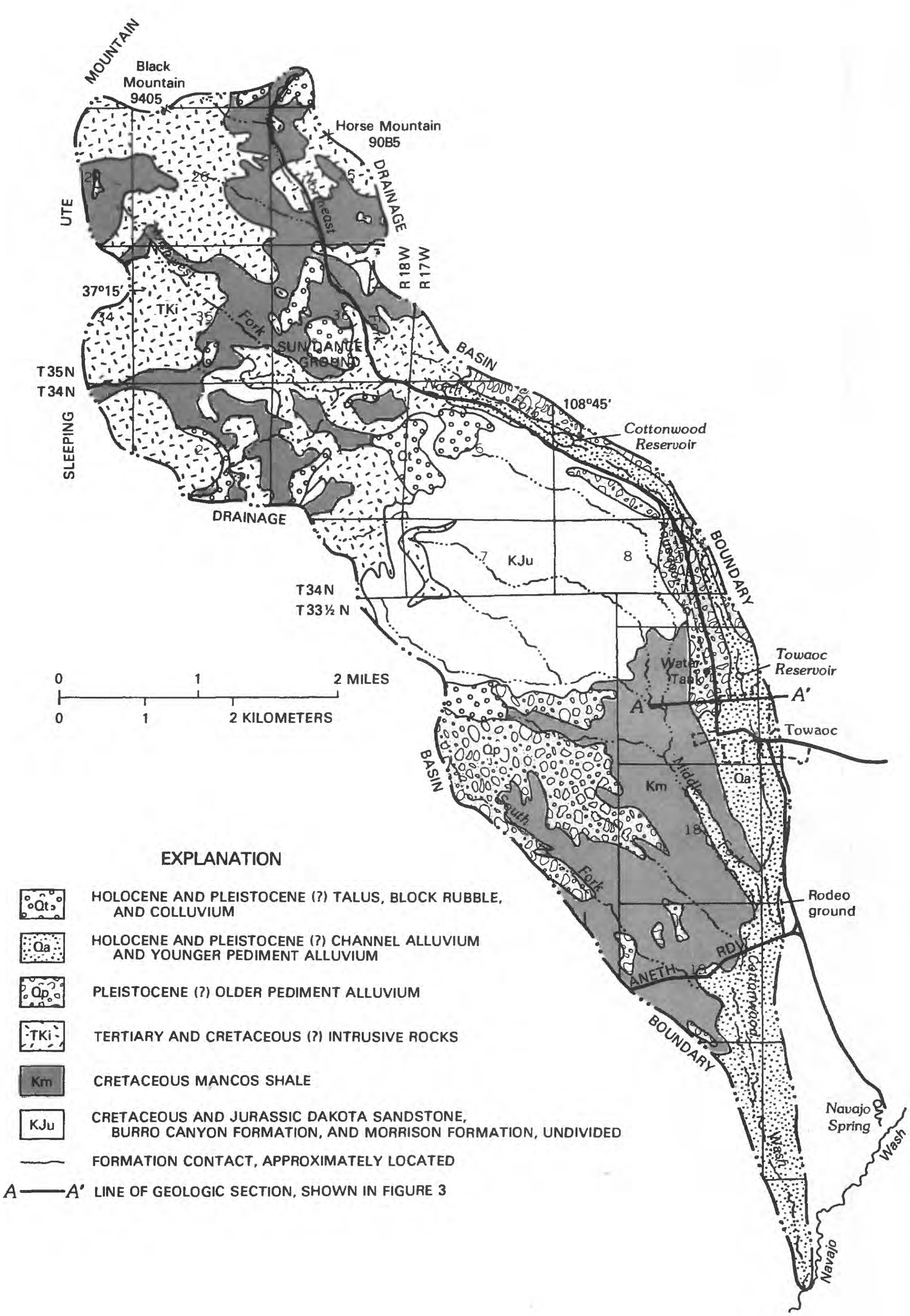


Figure 2.--Surficial geology. (Modified from Ekren and Houser, 1965, and Irwin, 1966).

Geology

Formations ranging in age from Precambrian to Quaternary underlie the area (table 1). Formations older than the Morrison Formation of Jurassic age do not crop out but are found in water wells and petroleum-industry exploration holes.

Formations ranging in age from Jurassic to Upper Cretaceous underlie a small area on the flank of Sleeping Ute Mountain (fig. 2). These formations include the Morrison Formation, Burro Canyon Formation, and Dakota Sandstone. Erosional remnants of the Dakota Sandstone also occur on Sleeping Ute Mountain.

The Mancos Shale of Upper Cretaceous age crops out between igneous intrusions forming Sleeping Ute Mountain and underlies pediment alluvium flanking the mountain. Much of the formation has been removed by erosion, and only the lower 200-900 ft remain. Two members of the formation, the Greenhorn Member, 75 ft above the base, and the Juana Lopez Member, 475 to 525 ft above the base, are predominantly limestone.

Sleeping Ute Mountain is formed by Cretaceous and Tertiary laccoliths, sills, dikes, and stocks. These intrusions are composed of diabase, diorite, granodiorite, and quartz monzonite.

Quaternary deposits in the area include talus, block rubble, colluvium, stream-channel alluvium, and pediment alluvium. Talus, block rubble, and colluvium cover much of the rock in the area but usually are too thin to be mapped separately. A thin, discontinuous deposit of alluvium occurs in the channel of Cottonwood Wash. Two pediment deposits flanking Sleeping Ute Mountain are the most extensive surficial deposits in the area.

A pediment is a gently inclined erosional surface extending from a mountain front to an adjacent valley. It consists of erosion-carved bedrock and a veneer of alluvium, which, together give the pediment a generally flat appearance when viewed at right angles to the mountain front. Successive uplifts of a mountain range rejuvenate streams, which may result in extensive dissection of old pediments and the formation of newer ones at lower altitudes.

The two pediments flanking Sleeping Ute Mountain (fig. 3) represent two periods of erosion, probably within the Wupatki cycle (Cooley and others, 1969) of middle and late Pleistocene age. The older pediment alluvium probably is no more than 40 ft thick; the younger pediment alluvium is 30 to 50 ft thick. The older pediment alluvium underlies a terrace adjacent to Cottonwood Wash upstream from Towaoc and caps knobs of Mancos Shale downstream from Towaoc. The younger pediment alluvium is entrenched into the older deposit upstream from Towaoc and extends around knobs of Mancos Shale into adjacent arroyos downstream from Towaoc. The older pediment alluvium consists of gravel, cobbles, and boulders in silty sand. The younger pediment alluvium changes from mostly coarse gravel to mostly sand downgradient and is capped by clay adjacent to knobs of Mancos Shale.

Alluvium deposited in the modern channel of Cottonwood Wash represents a third period of erosion. This alluvium, which is Holocene in age, probably is no more than 10 ft thick. It consists of sand, gravel, cobbles, and boulders.

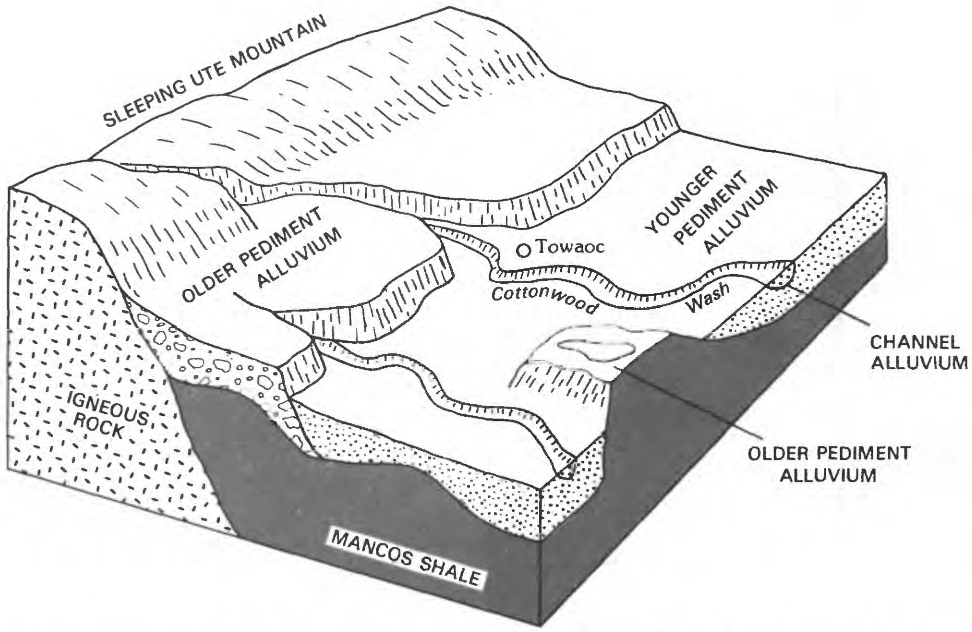
Table 1.--*Generalized description of the physical and water-supply characteristics of geologic formations in Cottonwood Wash watershed*

[Modified from Irwin, 1966, p. 14-15, and Weir and others, 1983, table 3, using unpublished petroleum-industry information and isopach maps in Andrews and others, 1983]

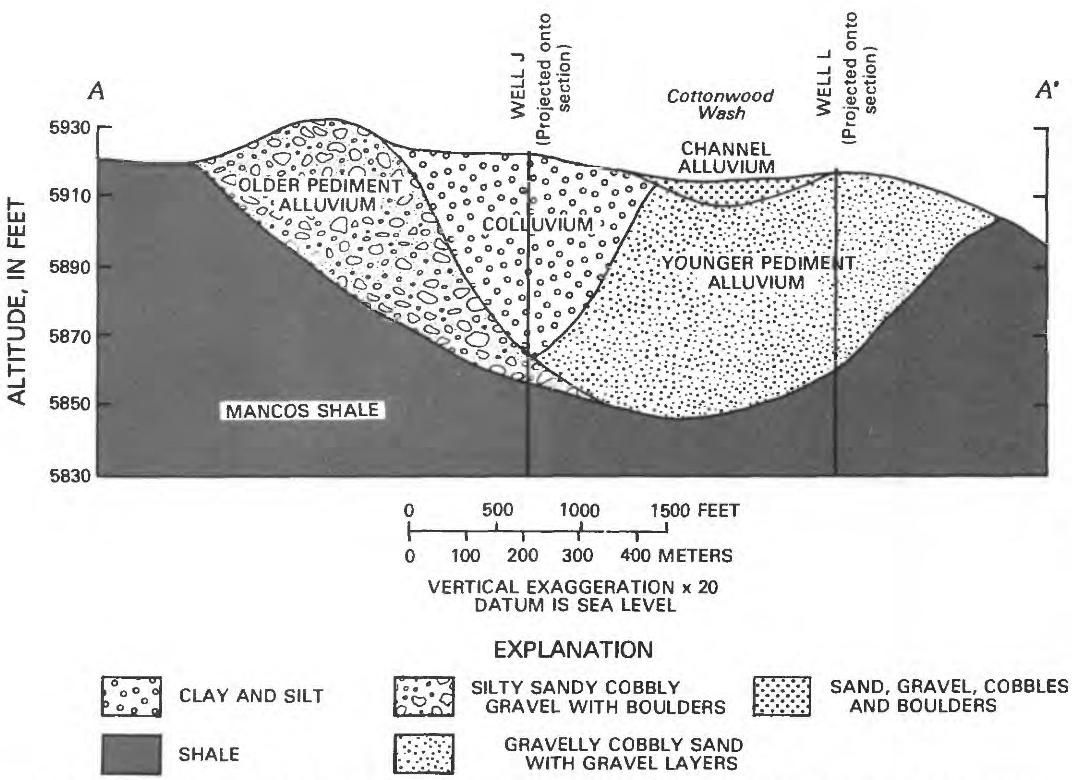
System	Series	Group	Formation	Member	Thickness (feet)	Physical characteristics	Water supply
Quaternary	Holocene(?)		Alluvium		10(?)	Silt, sand, gravel, and cobbles in channels of Cottonwood Wash. Gravels and cobbles are fragments of igneous rocks from Sleeping Ute Mountain.	Yields small (usually less than 10 gallons per minute) quantities of water to wells.
	Holocene and Pleistocene(?)		Talus deposits			Predominantly igneous rocks, as much as 10 feet in diameter, on steep slopes.	Yields small to large (less than 10 to 100 gallons per minute) quantities of water to springs at base of unit.
	Pleistocene(?)		Pediment deposits		30-50	Silt to boulder-sized detritus in terraces on flanks of Sleeping Ute Mountain.	Yields small to moderate (less than 10 to 50 gallons per minute) quantities of water to wells and springs.
Tertiary and Cretaceous(?)			Intrusive rocks			Laccoliths, dikes, sills, and stocks ranging from diabase to quartz monzonite in composition.	Not water-yielding.
Cretaceous	Upper Cretaceous		Mancos Shale		200-900	Gray to black shale with thin beds of limestone and limestone concretions.	Yields small quantities of slightly saline water, mainly from the Juana Lopez and Greenhorn Limestone Members, 500 and 75 feet above the base of the formation.
			Dakota Sandstone		100-160	Light gray to tan, fine- to medium-grained sandstone with interlayered shale and coal.	Yields small to moderate quantities of water to wells and springs.
	Lower Cretaceous		Burro Canyon Formation		0-200	Light gray to white sandstone and conglomerate with interlayered red and green mudstone.	
Jurassic	Upper Jurassic		Morrison Formation		500-700	Red and green shale with interlayered green to tan sandstone and siltstone.	Salt Wash and Westwater Canyon Sandstone Members may yield small quantities of water to wells.
	Middle Jurassic		Junction Creek Sandstone		230-260	Pink to light brown, fine- to medium-grained sandstone.	Yields small to moderate quantities of water to wells.
		San Rafael Group	Wanakah Formation		100-160	Pink to red-brown, thin-bedded, siltstone, sandstone, and mudstone.	Not water-yielding.
			Entrada Sandstone		60-80	White, tan, and orange, fine-grained sandstone.	Yields small quantities of water to wells.
			Carmel Formation		20-25	Red-brown siltstone and silty sandstone.	Not water-yielding.

Table 1.--*Generalized description of the physical and water-supply characteristics of geologic formations in Cottonwood Wash watershed*--Continued

System	Series	Group	Formation	Member	Thickness (feet)	Physical characteristics	Water supply
Jurassic and Triassic(?)	Lower Jurassic and Upper Triassic(?)	Glen Canyon Group	Navajo Sandstone		0-300	White, tan, and orange, fine-grained, cross-bedded sandstone.	Yields small quantities of water to wells.
Triassic	Upper Triassic	Glen Canyon Group	Kayenta Formation		0-10	Red and white mudstone, siltstone, and sandstone.	Yields small quantities of water to wells.
Triassic	Upper Triassic	Glen Canyon Group	Wingate Sandstone		20-50	Massive orange, fine-grained sandstone.	Yields small quantities of water to wells.
Triassic	Upper Triassic		Chinle Formation		700-800	Variegated shale with sandstone and conglomerate layers.	Sandstone and conglomerate layers yield small to large quantities of water to wells.
Triassic	Middle and Lower Triassic		Moenkopi Formation		50-100	Red-brown siltstone, mudstone, and sandstone.	Generally not water-yielding.
Permian	Lower Permian		De Chelly Sandstone		0-50	Massive orange sandstone.	Yields small quantities of water to wells.
Permian	Lower Permian		Cutler Formation		1,650-1,750	Red arkosic sandstone, siltstone, and shale.	Yields small quantities of water to wells.
Pennsylvanian	Upper and Middle Pennsylvanian		Hermosa Formation	Upper Member	950-1,100	Gray limestone with sandstone and shale layers.	Yields small quantities of water to wells.
Pennsylvanian	Upper and Middle Pennsylvanian		Hermosa Formation	Paradox Evaporite Member	1,500-2,000	Interbedded gypsum, halite, shale, carbonate rocks, and sandstone.	Generally not water yielding, but carbonate layers may yield water, oil, or gas.
Pennsylvanian	Upper and Middle Pennsylvanian		Hermosa Formation	Lower Member	100-150	Gray limestone and shale.	Generally not water yielding.
Pennsylvanian	Lower Pennsylvanian		Molas Formation		50-100	Red shale and siltstone with limestone layers.	Generally not water yielding.
Mississippian			Leadville Limestone		180-220	Gray limestone and dolomite.	Yields small to large quantities of water to wells, mostly from fractures, karst features, and dolomite layers.
Devonian	Upper Devonian		Ouray Formation		75-85	Gray limestone and dolomite.	Yields small to large quantities of water to wells, mostly from fractures, karst features, and dolomite layers.
Devonian	Upper Devonian		Elbert Formation		200-250	Dolomite, quartzite, glauconitic sandstone, and shale.	May yield small quantities of water from fractures.
Cambrian	Upper Cambrian		Lynch Dolomite(?)		100-250	Gray dolomite with green and gray siltstone.	May yield small quantities of water from fractures.
Cambrian	Upper Cambrian		Ignacio Quartzite		100-250	Pink to light gray quartzite and sandstone.	May yield small quantities of water from fractures.
Precambrian	X		Undivided			Granitic rocks.	May yield small quantities of water from fractures.



A. SCHEMATIC ILLUSTRATION OF PEDIMENT AND CHANNEL ALLUVIUM NEAR TOWAOC, COLORADO.



B. GEOLOGIC SECTION ACROSS COTTONWOOD WASH (LOCATION SHOWN ON FIGURE 2)

Figure 3.--Stratigraphic relations between alluvium and bedrock: *A*, Schematic illustration of pediment and channel alluvium near Towaoc, Colo.; *B*, Geologic section across Cottonwood Wash.

Climate

Recharge to aquifers in the Four Corners area is inhibited by generally sparse precipitation. Weather was not monitored during the study. However, climate patterns in the region are fairly uniform, and records from established weather stations allowed estimation of precipitation and temperature in the Cottonwood Wash watershed. Eleven precipitation-measuring stations, each with at least 15 years of record, were considered acceptable for this analysis. These stations are all operated by the National Oceanic and Atmospheric Administration (NOAA).

Selected NOAA stations extend from the Four Corners Platform and northern San Juan Basin to the San Juan Mountains (see fig. 1). Because of rain-shadow effects, precipitation stations east of the crest of the San Juan Mountains were not used. The closest station to the study area, Mesa Verde National Park, Colo., is about 13 mi away; the farthest station, Pagosa Springs, Colo., is about 95 mi away. Silverton, Colo., at an altitude of 9,322 ft, is the highest station; Shiprock, N. Mex., at an altitude of 4,870 ft, is the lowest station. The station near Cortez, Colo., 15 mi from the study area and 6,212 ft in altitude, is considered to have the climate most similar to the central part of the Cottonwood Wash watershed.

Precipitation and temperature in the Four Corners area are influenced strongly by altitude (figs. 4A and 4B). Application of the regression equations indicated in figures 4A and 4B to altitudes in the study area indicates that average annual precipitation increases from 8.4 in. at the mouth of Cottonwood Wash to 29 in. at the top of Sleeping Ute Mountain; average annual temperature decreases in that direction from 57.5°F to 36.3°F (fig. 5).

Monthly precipitation and temperature can also be estimated from NOAA data. When average monthly climate statistics at stations spanning the range in altitude in the Cottonwood Wash watershed are plotted against the same statistics at Cortez, the resulting curves (figs. 4C and 4D) define monthly altitude-dependent climate patterns. These curves may be used to estimate the precipitation or temperature at any site in the Four Corners area from the equivalent recorded statistic at Cortez.

As an example of use, suppose one wanted to know the January 1982 precipitation at an altitude of 6,000 ft in the Cottonwood Wash watershed. The first step would be to locate the January 1982 precipitation at Cortez (listed in National Oceanic and Atmospheric Administration climatic records) on the x-axis. Projecting upward to curves spanning the altitude of interest, one would calculate values of January precipitation at altitudes of 5,100 ft and 6,700 ft. Interpolation between these values would yield a precipitation value at the altitude of interest.

This method was used to estimate average monthly precipitation and temperature in the central part of the Cottonwood Wash watershed (at an altitude of 6,978 ft) on the basis of average monthly data at Cortez. The estimated statistics are listed in table 2. The sums of the estimated monthly averages differ slightly from the estimated annual averages determined from figures 4A and 4B because the two methods of estimation are not precise. Differences are resolved by averaging.

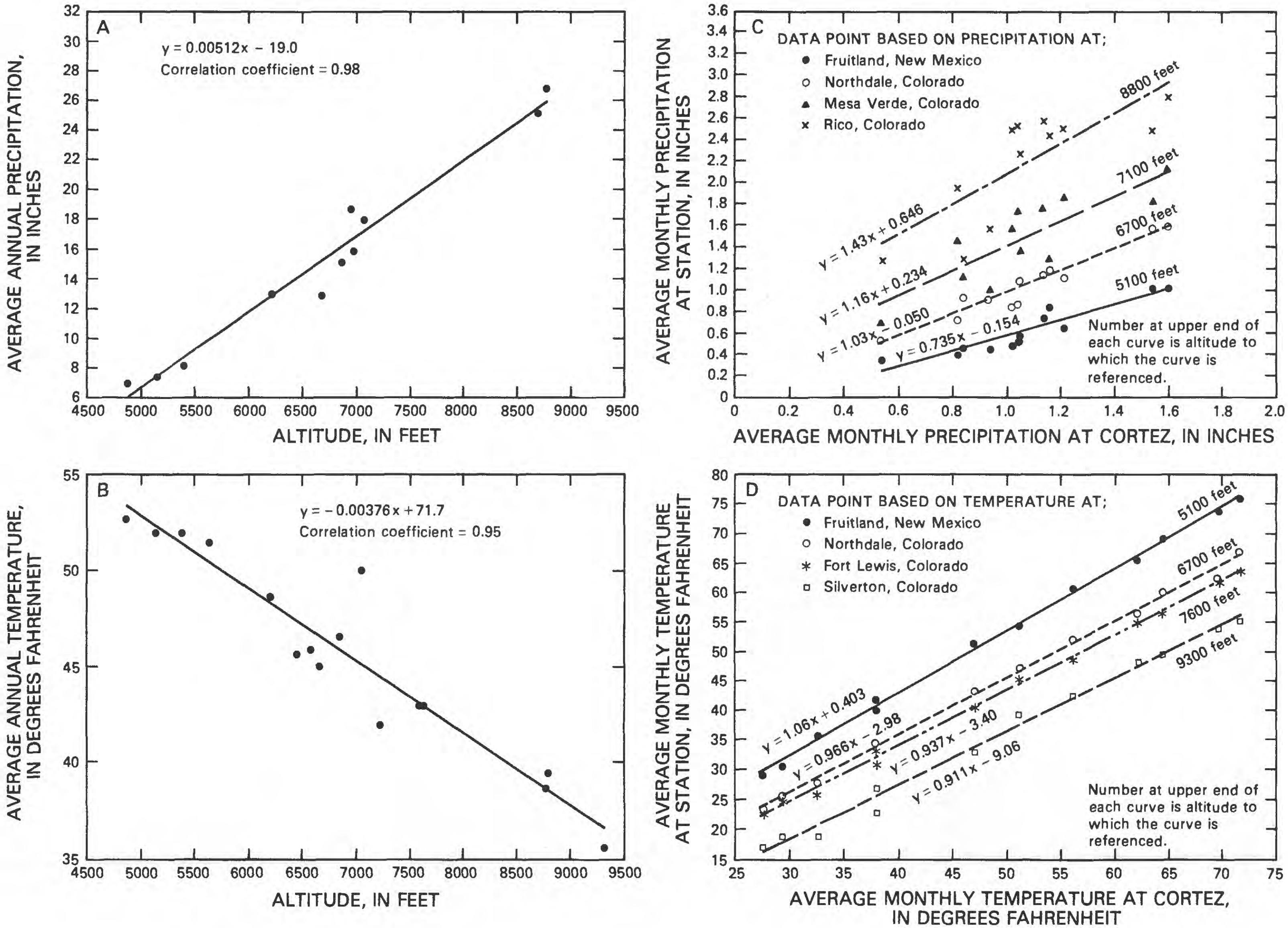


Figure 4.--Relations of precipitation and temperature to altitude in the Four Corners area, 1930-80.

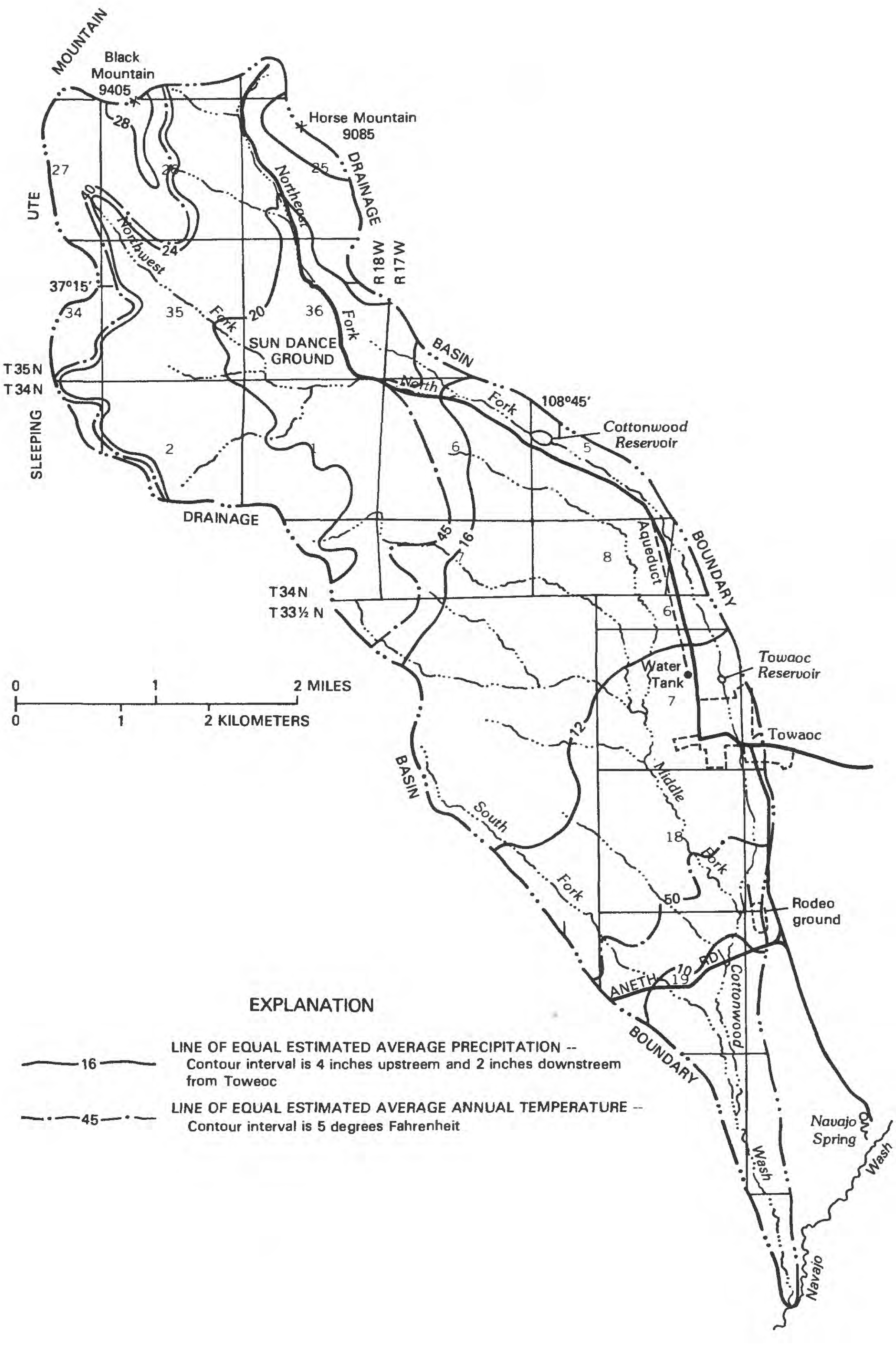


Figure 5.--Estimated average annual precipitation and temperature, 1930-80.

Table 2.--*Estimated average climatological statistics*

	Temperature (degrees Fahrenheit)	Precipitation (inches)	Solar radiation langleys per day)	Actual evapotranspiration (inches)	Potential evapotranspiration (inches)[3]
January------	23.0	1.49	350	0.84	0.8
February-----	27.7	1.14	470	.56	1.5
March--------	32.8	1.47	500	.32	3.1
April--------	41.4	1.41	700	.28	5.1
May----------	50.1	1.38	770	.82	7.6
June---------	57.8	.83	790	1.68	9.4
July---------	64.7	1.51	760	1.65	10.8
August-------	62.8	2.03	680	1.75	9.4
September----	55.6	1.53	580	.66	6.4
October------	45.3	2.06	460	.71	3.9
November-----	32.8	1.27	360	.64	1.8
December-----	24.5	1.69	300	.68	.8
Annual-------	[1]43.3 [2]45.5	[1]17.2 [2]16.7	570	10.59	60.6

[1]Calculated from monthly averages.
[2]Calculated from mean averages.
[3]Calculated using Jensen-Haise equation (American Society of Civil Engineers, 1974, p. 73-74).

An additional climatological statistic, actual evapotranspiration, was estimated with the U.S. Geological Survey Precipitation Runoff Modeling System (Leavesley and others, 1983). This computer model estimates outflows from a hydrologic system on the basis of the physical characteristics of the watershed and hydrologic principles. One of the input parameters for the model is solar radiation. Solar radiation was monitored by the U.S. Geological Survey at Kimbeto, N. Mex., from 1978 to 1982. Although Kimbeto is 84 mi from Towaoc, its similar physiographic setting allows one to assume that solar radiation there and at Towaoc are similar; estimates of average monthly solar radiation based on this assumption and average actual evapotranspiration calculated by the Precipitation Runoff Modeling System are listed in table 2 also.

In an average year, an estimated 17 in. (14,600 acre-ft) of precipitation falls in the Cottonwood Wash watershed. The wettest months generally are July to October (table 2), when precipitation occurs mostly as localized thunderstorms. June is the driest month. Precipitation is about evenly distributed from November to May, when regional storms of extended duration pass through the area. During most of April to September, evapotranspiration exceeds precipitation, resulting in net moisture deficits (fig. 6).

During the 1982 water year, an estimated 16.9 in. of precipitation (14,500 acre-ft) fell in the Cottonwood Wash watershed (fig. 6). Eighty-six percent of this precipitation, or 12,500 acre-ft, is estimated to have been consumed by evapotranspiration. In contrast, estimated evapotranspiration losses during the three preceding water years ranged from 60 to 90 percent.

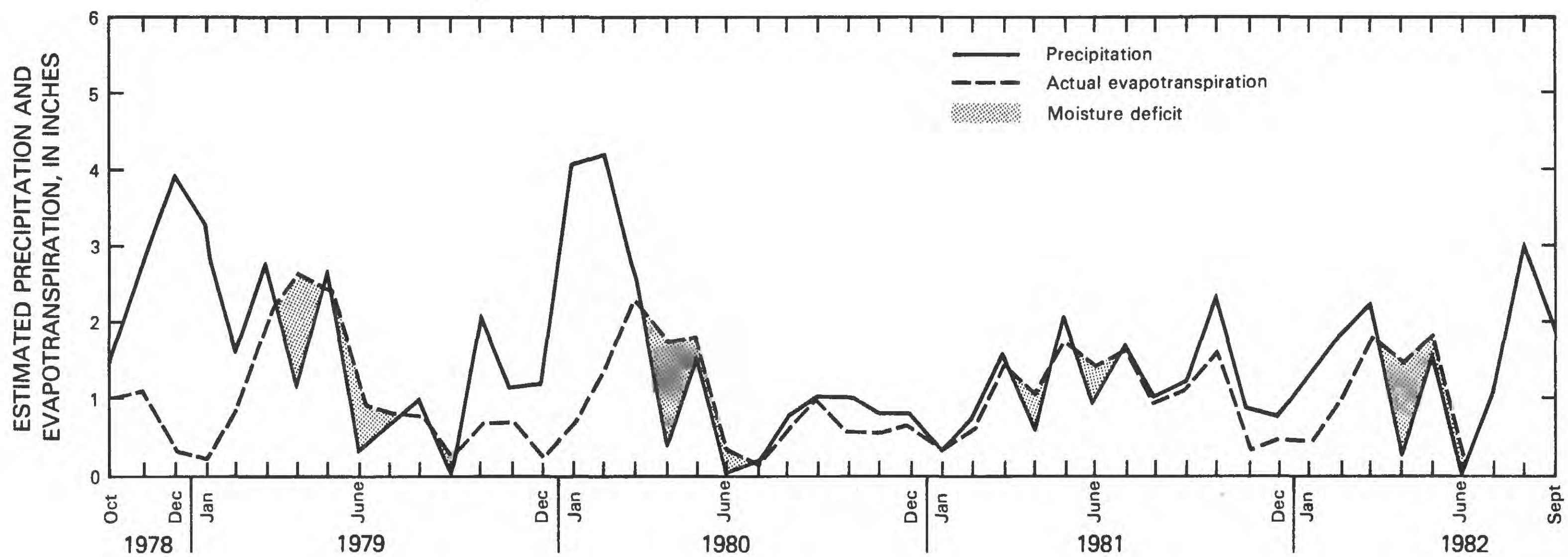


Figure 6.--Estimated monthly precipitation, evapotranspiration, and moisture deficits, calendar years 1978-82.

SURFACE WATER

Streamflow in Cottonwood Wash is ephemeral to intermittent. Upstream from Towaoc, runoff resulting from snowmelt, rainfall, and springs occurs year-round in parts of most channels (fig. 7).

All of the streamflow in the north fork upstream from Towaoc is intercepted by two reservoirs. Cottonwood Reservoir, 2.4 mi upstream, has a surface area of 1.94 acres and a storage capacity of 5.08 acre-ft (fig. 8). Streamflow is diverted to the reservoir by a short, headgate-controlled, unlined ditch. Overflow from Cottonwood Reservoir is contained by an in-channel reservoir 2.3 mi downstream, Towaoc Reservoir. All water stored in reservoirs that is not hauled away by residents of Towaoc eventually evaporates, seeps into underlying alluvium, or is consumed by bank vegetation.

Because of reservoir storage, Cottonwood Wash downstream from Towaoc is dry in most reaches during most of the year. Some runoff occurs from snowmelt, rainfall, and seasonal springs.

Springs

Springs flowing into Cottonwood Wash may be seasonal or perennial. Most springs have their largest discharges during the spring and early summer months, when the ground is saturated with moisture from snowmelt. Springs gradually release this moisture during succeeding months until much of it is depleted. Many springs cease flowing during the late summer and fall months.

Springs in the watershed upstream from Towaoc (fig. 9) contribute water to the wash, which either evaporates or seeps into the channel alluvium; springs in the watershed downstream from Towaoc discharge water from the channel alluvium, much of which evaporates or flows into adjacent drainages. Upstream from Cottonwood Reservoir, most springs originate from block rubble and talus, but some issue from older pediment alluvium (spring 9), Mancos Shale (spring 8), and colluvium overlying Mancos Shale (springs 1, 7, 10, and 11). Spring 8 issues from the axial region of a small syncline and probably is localized by the fold.

During the 1982 water year, 17 springs were identified in the Cottonwood Wash watershed and in arroyos hydraulically connected to it by contiguous pediment alluvium (table 3). Discharge measurements of streamflow in Cottonwood Wash indicate that a substantial quantity of diffuse seepage into the wash exists during the spring months. Most of this unidentified inflow probably is from pediment alluvium. Because Cottonwood Wash upstream from Cottonwood Reservoir has several losing reaches, some of the unidentified inflow probably is seepage from channel alluvium.

In May and June 1982, the combined flow from the 11 identified springs upstream from Cottonwood Reservoir (fig. 9) was calculated to be 350 gal/min (0.78 ft^3/s). Diffuse seepage contributed an additional 243 gal/min (0.54 ft^3/s) to the wash. Of this springflow and seepage, 574 gal/min (1.28 ft^3/s) was diverted to Cottonwood Reservoir, and 22 gal/min (0.05 ft^3/s) remained in the channel.

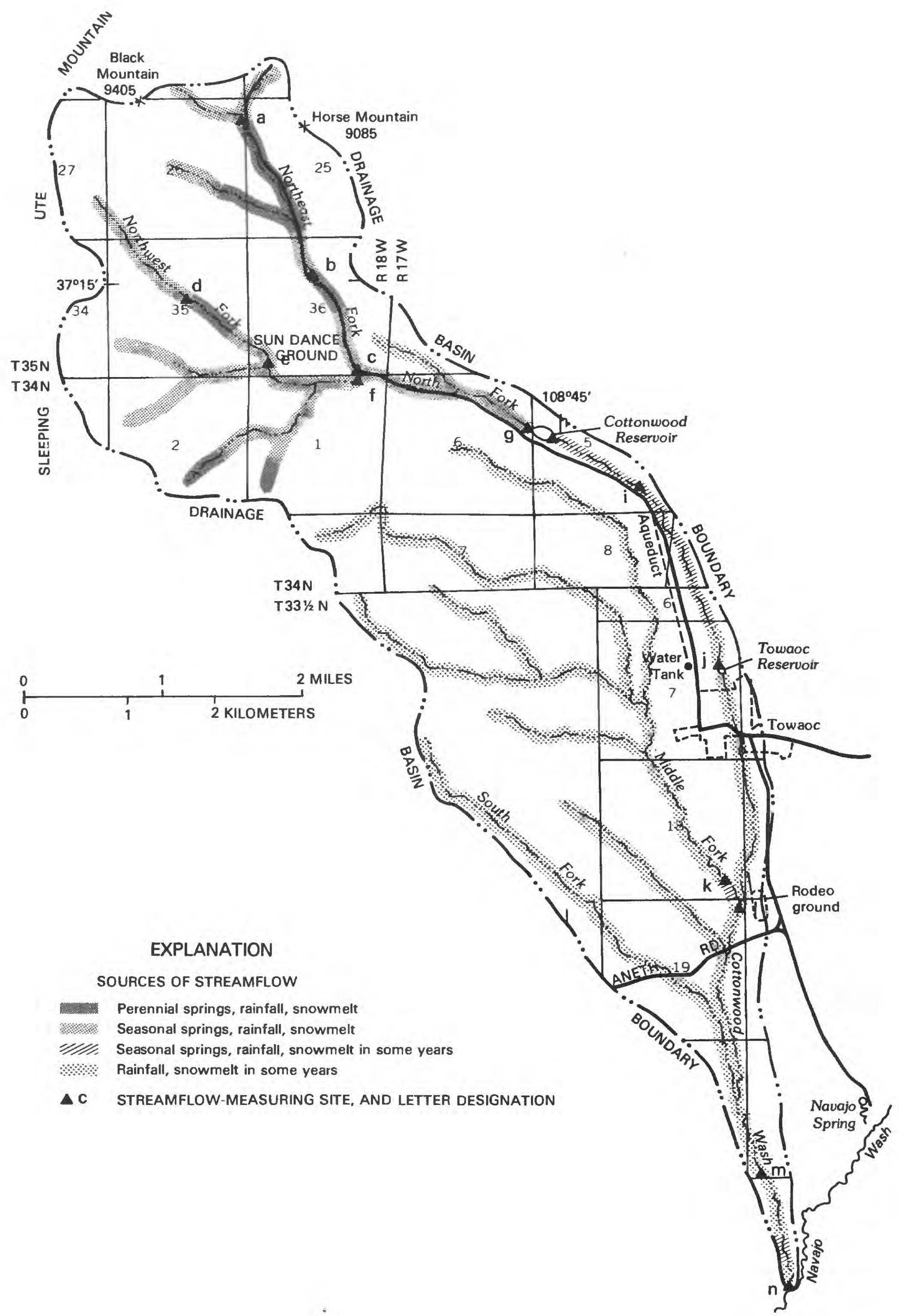
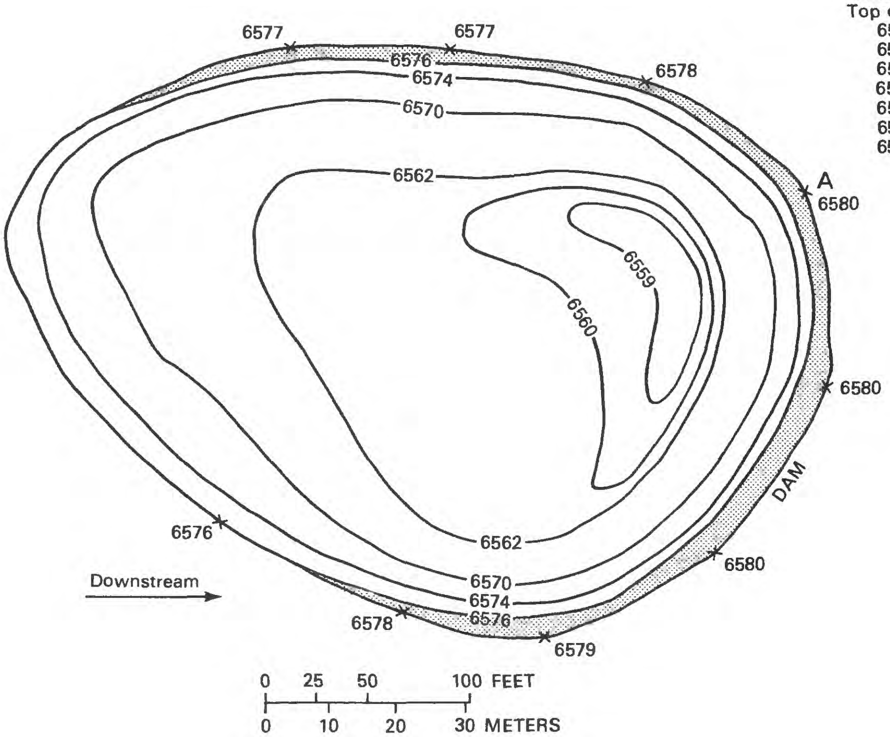


Figure 7.--Sources of streamflow and discharge-measurement sites.

STORAGE CAPACITY TABLE

Altitude (feet)	Surface area (acres)	Storage (acre-feet)
Top of dam	2.07	5.08
6576	1.94	5.08
6574	1.74	3.24
6570	1.36	1.69
6562	0.74	0.64
6560	0.21	0.16
6559	0.06	0.03
6558	0.00	0.00



EXPLANATION

—— 6570 —— LINE OF EQUAL GROUND-SURFACE ALTITUDE -- Contour interval, in feet, is variable. Altitudes were determined relative to point A with a pocket transit and steel tape. The altitude of point A was determined from the U,S. Geological Surver Mariano Wash East 1:24,000 topographic quadrangle map,

NO STORAGE CAPACITY

Figure 8.--Bottom configuration and storage capacity of Cottonwood Reservoir, November 1982.

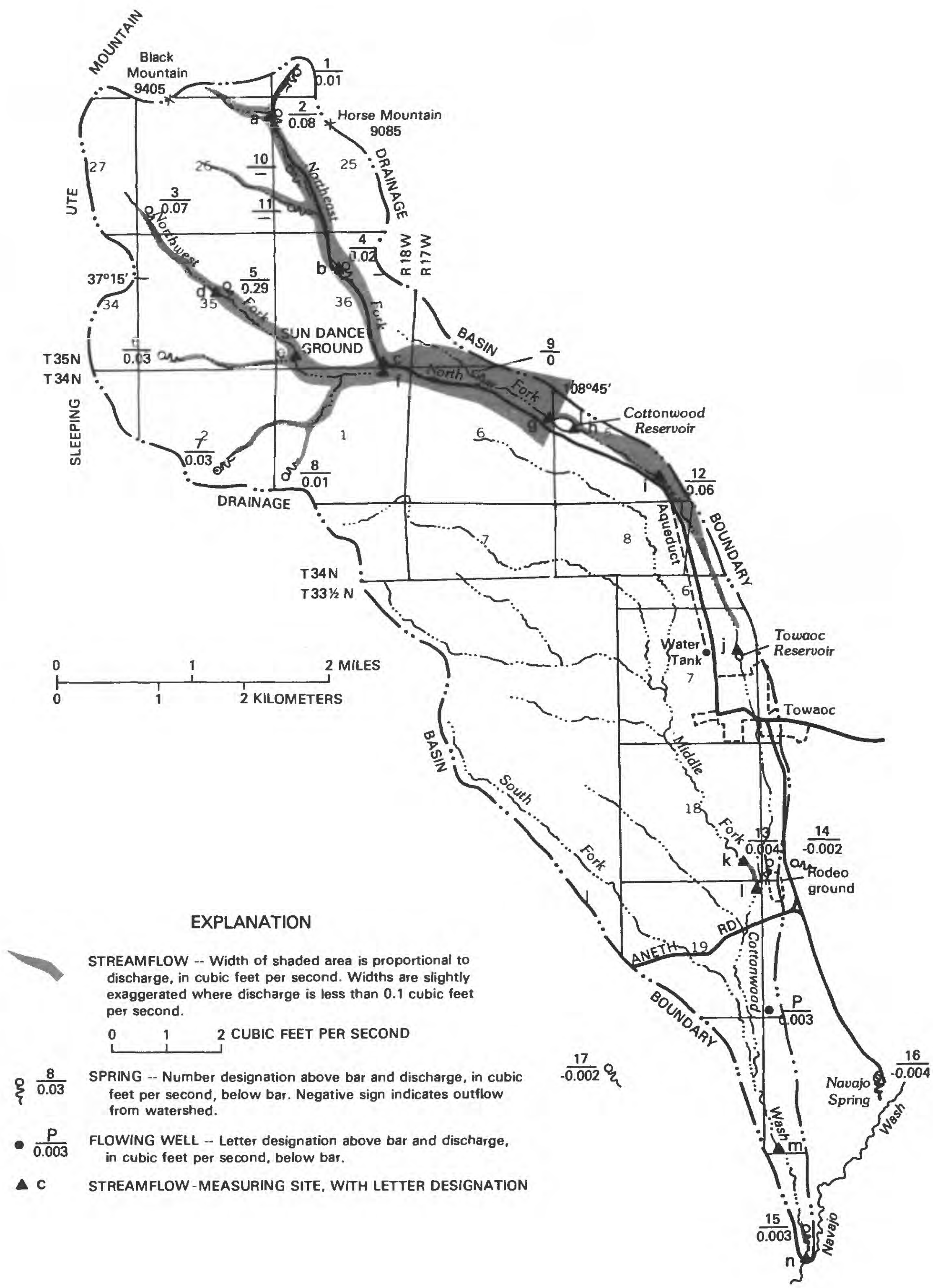


Figure 9.--Streamflow and discharge from springs and flowing wells, May 26-27, 1982.

Table 3.--*Records of identified springs in Cottonwood Wash watershed and hydraulically connected arroyos, 1982-83*

[See figure 13 in Supplemental Information section at back of report for system of numbering spring locations]

Site designation	Location number	Altitude (feet)	Geologic source	Discharge: Date	Discharge: Gallons per minute	Discharge: Cubic feet per second	Remarks
			Upper Wash (upstream from Cottonwood Reservoir)				
1	NB03501824CCC	8,160	Colluvium overlying Mancos Shale.	5/26/82	5.2	0.012	
				8/18/82	0	0	
				10/12/82	0	0	
				1/20/83	.5 (est)	.001 (est)	
2	NB03501825BBC	8,080	Block rubble overlying diorite porphyry.	5/26/82	34	.076	
				8/18/82	5.8	.013	
				10/12/82	2.8	.0062	
				1/20/83	7 (est)	.02 (est)	
3	NB03501827DAA	8,560	Block rubble overlying Mancos Shale.	8/13/57	20	.045	Designated S-8 spring by Irwin (1966).
				6/10/82	34	.076	
				8/17/82	0	0	
				10/12/82	0	0	
				1/20/83	2 (est)	.004 (est)	
4	NB03501836BAD	7,400	Block rubble overlying diorite porphyry.	5/26/82	11	.025	
				8/18/82	5.8	.013	
				10/12/82	4.5	.010	
				1/20/83	13	.029	
				4/04/83	14	.031	
5	NB03501835ACC	7,800	Block rubble overlying Juana Lopez Member of Mancos Shale.	8/13/57	20	.045	Juana Lopez Spring; designated S-3 spring by Irwin (1966); spring flows into concrete cistern and troughs.
				5/27/82	131	.29	
				6/09/82	80	.18	
				8/18/82	7.6	.017	
				10/12/82	3.2	.0071	
				1/20/83	5.5	.012	
6	NB03501835CCC	8,120	Block rubble overlying Mancos Shale.	8/13/57	5	.011	Designated S-4 spring by Irwin (1966); spring flows into concrete troughs.
				6/10/82	12	.027	
				8/17/82	1.6	.0036	
				10/12/82	0	0	
				1/20/83	2 (est)	.004 (est)	
7	NB03401802DAB	7,960	Colluvium overlying Mancos Shale.	5/27/82	12	.027	Breached dam on site.
				8/18/82	.27	$6x10^{-4}$	
				10/12/82	.47	.0010	
				1/20/83	1 (est)	.002 (est)	
8	NB03401801CBC	7,860	Mancos Shale and colluvium.	5/27/82	5.8	0.013	Some of the water issues from pipes.
				8/18/82	.84	.0019	
				10/12/82	.40	$9x10^{-4}$	
				1/20/83	1 (est)	.002 (est)	

Table 3.--*Records of identified springs in Cottonwood Wash watershed and hydraulically connected arroyos, 1982-83*--Continued

Site designation	Location number	Altitude (feet)	Geologic source	Discharge: Date	Discharge: Gallons per minute	Discharge: Cubic feet per second	Remarks
			Upper Wash (upstream from Cottonwood Reservoir)--Continued				
9	NB03401706BAA	6,850	Older pediment alluvium.	8/13/57	5	.011	Tom Root Spring; designated S-1 spring by Irwin (1966); spring flows from shed into troughs.
				5/05/82	1 (est)	.002 (est)	
				5/26/82	0	0	
				8/18/82	0	0	
				10/12/82	.005	$1x10^{-5}$	
				1/10/83	0	0	
				4/04/83	2.2	.0049	
10	NB03501825BCC	7,960	Block rubble and colluvium overlying Mancos Shale.	8/22/57	10	.022	Designated S-7 spring by Irwin (1966).
				5/27/82	52 (est)	.115 (est)	
				8/18/82	10 (est)	.022 (est)	
				10/13/82	5 (est)	.011 (est)	
11	NB03501825CCB	7,860	Block rubble and colluvium overlying Mancos Shale.	8/22/57	10	.022	Designated S-5 spring by Irwin (1966).
				5/27/82	52 (est)	.115 (est)	
				8/18/82	10 (est)	.022 (est)	
				10/13/82	5 (est)	.011 (est)	
			Lower Wash (downstream from Cottonwood Reservoir)				
12	NB03401705DCA	6,365	Younger pediment alluvium.	5/26/82	26	.058	Designated G-1 spring by Irwin (1966); spring flows into infiltration gallery.
				8/17/82	9.4	.021	
				10/12/82	3.3	.0074	
				1/10/83	8.6	.019	
				4/04/83	43	.096	
13	NB03301717UCCB	5,680	Younger pediment alluvium.	5/25/82	2	.0045	Designated G-2 spring by Irwin (1966); spring flows through a sump into Cottonwood Wash.
				8/17/82	0	0	
				10/13/82	0	0	
				1/10/83	2.1	.0047	
14	NB03301717UCDC	5,660	Younger pediment alluvium, Mancos Shale.	5/25/82	<1 (est)	<.002 (est)	Several seeps.
15	NB03301732UBDB	5,390	Channel alluvium overlying Mancos Shale.	6/08/82	1.5	0.0033	
				8/17/82	2	.0045	
				10/13/82	0	0	
				1/10/83	0	0	
16	NB03301729UADC	5,470	Younger pediment alluvium.	1/18/54	5	.011	Navajo Spring; designated S-15 spring by Irwin (1966); spring flows from shed into house and stock trough.
				5/ 60	0	0	
				5/25/82	1.9	.0042	
				10/13/82	0	0	
				1/10/83	.4	$9x10^{-4}$	
17	NB03301825UACC	5,580	Younger pediment alluvium.	5/25/82	<1 (est)	<.002 (est)	Designated S-16 spring by Irwin (1966); spring flows into trough.
				10/24/82	0	0	

Between Cottonwood Reservoir and Towaoc, reservoir leakage and seepage from pediment alluvium produced 219 gal/min (0.49 ft^3/s) of streamflow in the wash. Virtually all of this flow seeped back into the alluvium. However, the discharge from spring 12, 26 gal/min (0.06 ft^3/s), was diverted by way of an infiltration gallery and aqueduct to a storage tank at Towaoc to augment supplies from the Dolores River.

Downstream from Towaoc, distributary springs, two in the Cottonwood Wash watershed and three in adjacent arroyos, cumulatively discharged about 7 gal/min (0.02 ft^3/s), most of which immediately seeped back into the alluvium. However, the discharge from spring 16 (Navajo Spring) was diverted to an adjacent house for domestic use.

During the 1982 water year, discharge from springs and seeps in the watershed decreased by 97 percent between May and October. Many of the springs visited in May were no longer flowing in October. The combined flow from all springs in October was about 25 gal/min (0.06 ft^3/s). The estimated cumulative flow of all tributary springs and seeps during the 1982 water year was 290 acre-ft, based on quarterly measured and estimated discharges.

This study was not designed to determine long-term variations in flow from individual springs, but observations indicate that variations in the snowpack on Sleeping Ute Mountain affect the discharges from springs. The snowpack during the 1983 water year was larger and remained on the ground longer than during the previous water year, and the discharges from springs 4, 9, and 12 in the spring of 1983 were larger than in the spring of 1982.

The largest springs in the watershed generally issue from block rubble and talus. From May 1982 to January 1983, measured discharges from spring 5 (Juana Lopez Spring) ranged from 3.2 to 131 gal/min (0.007 to 0.29 ft^3/s, table 3). During the same period, measured discharges from spring 2 ranged from 2.8 to 34 gal/min (0.006 to 0.08 ft^3/s), and measured discharges from spring 4 ranged from 4.5 to 13 gal/min (0.01 to 0.03 ft^3/s). At certain times of the year, discharges from springs 2, 4, and 5 exceeded that of spring 12, which is the only spring developed for municipal use. During the spring and summer months, spring 5 had the largest discharge in the watershed. However, flow from this spring decreased substantially throughout the rest of the year. During the fall and winter, its discharge was exceeded by springs 2, 4, and 12. Spring 4 had the largest discharge during the fall and winter months.

Two of the springs in the watershed, springs 12 and 13, were created by the residents of Towaoc and subsequently used to augment municipal water supplies. Spring 12 resulted from construction of an infiltration gallery in the younger pediment alluvium during the early 1950's. Initial discharges from this spring ranged from a few gallons per minute to 35 gal/min (0.08 ft^3/s), but after 1957, when Cottonwood Reservoir was built 0.7 mi upstream, discharges increased to as much as 100 gal/min (0.22 ft^3/s). Leakage from Cottonwood Reservoir apparently recharges the alluvium supplying water to spring 12 (Irwin, 1966, p. 60). Measured discharges from spring 12 ranged from 3.3 to 43 gal/min (0.007 to 0.10 ft^3/s) during the 1982 and 1983 water years (table 3).

Spring 13 was created accidently, when construction of a racetrack 1 mi south of Towaoc breached the water table. The water from this spring formerly was collected in a sump and pumped to Towaoc to augment municipal supplies. In May 1982, the pump was corroded beyond repair, and the spring was discharging through alluvium into Cottonwood Wash. Measured discharges from spring 13 ranged from 0 to 2.1 gal/min (0 to 0.005 ft^3/s) during the 1982 and 1983 water years.

Three springs, 14, 16, and 17, issue from arroyos adjacent to the Cottonwood Wash watershed that are hydraulically connected to it by contiguous pediment alluvium. Spring 14 occurred when construction of sewage lagoons downstream from Towaoc breached the water table. This spring consists of several small seeps that are estimated to cumulatively discharge less than 1 gal/min (less than 0.002 ft^3/s). Spring 16 (Navajo Spring) discharged 0 to 1.9 gal/min (0 to 0.004 ft^3/s) during the 1982 and 1983 water years. Seepage from spring 17 was too small to measure in May 1982 and was absent in October 1982.

Irwin (1966, p. 61) reports that discharges from spring 16 and several others nearby decreased substantially after construction of the racetrack south of Towaoc and development of spring 13. Spring 16 had a discharge of 5 gal/min (0.011 ft^3/s) in January 1954, three years before the racetrack was built (Irwin, 1966, p. 58-60). The discharge from spring 17 before the racetrack was built is unknown, but the springflow may have been large enough at some time to provide water for an adjacent prehistoric settlement. The ruins of this settlement, which may be contemporaneous with dwellings at Mesa Verde, cover approximately 3 acres.

Surface Runoff

Because most of the runoff in Cottonwood Wash is contained by reservoirs, there is little surface flow during most of the year. The most sustained runoff occurs from April to June, when the ground is saturated from snowmelt, and when springs and seeps issuing from talus, block rubble, colluvium, and alluvium have their largest discharges and maximum distribution. This "snowmelt" runoff at sites g and i upstream from Towaoc Reservoir (fig. 7) totaled 1.82 ft^3/s (817 gal/min) on May 27, 1982, and 1.00 ft^3/s (449 gal/min) on June 8, 1982, (table 4). Concurrently, the discharge in the Mancos River 12 mi south of Towaoc was 10 times greater than in Cottonwood Wash (which flows into the Mancos River through Navajo Wash). Based on this relationship and the recorded discharge of the Mancos River south of Towaoc, the peak of the "snowmelt" runoff in Cottonwood Wash during the 1982 water year is estimated to have been about 4.5 ft^3/s (2,020 gal/min). This peak probably occurred about May 5, 1982. Recession from the peak lasted about 100 days. Several weeks prior to the estimated peak of the "snowmelt" runoff during the next water year, the measured discharge in Cottonwood Wash at site i was 7.17 ft^3/s (3,220 gal/min).

Table 4.--*Measured streamflows in Cottonwood Wash, 1982-83*

Site designation	May 1982		June 1982		August 1982		October 1982		January 1983		April 1983	
	Day	Discharge (cubic feet per second)	Day	Discharge (cubic feet per second)	Day	Discharge (cubic feet per second)	Day	Discharge (cubic feet per second)	Day	Discharge (cubic feet per second)	Day	Discharge (cubic feet per second)
a	26	0.13	--	----	18	0	12	0	--	----	--	----
b	26	.44	--	----	18	0	12	0	20	0.05	4	2.05
c	27	.25	--	----	18	0	12	0	--	----	4	1.60
d	27	.14	--	----	18	0	12	0	--	----	--	----
e	27	.17	--	----	--	-	--	-	--	----	4	.72
f	27	.47	--	----	18	0	12	0	--	----	4	1.89
g	27	1.33	8	0.90	17	0	12	0	10	.01	4	5.60
h	27	.01	--	----	--	-	12	0	10	0	4	6.86
i	27	.50	8	.10	17	0	12	0	10	0	4	7.17
j	27	0	--	----	17	0	12	0	10	0	4	2.21
k	27	0	--	----	--	-	--	-	--	----	--	----
l	27	0	--	----	17	0	12	0	10	0	7	1.42
m	27	0	--	----	--	-	--	-	--	----	--	----
n	27	0	--	----	17	0	12	0	10	0	7	1.28

During most of the year, there is little or no flow in Cottonwood Wash, except near springs. During the summer and early fall, spring discharges are at the minimum for the year, but local rainstorms may produce runoff of short duration that exceeds the peak of the "snowmelt" runoff. From late fall to early spring, the ground generally is frozen in the upper wash, and surface flow is derived mainly from snowmelt on warm days. In the lower wash during the winter months, rainfall and a few small springs produce the only runoff.

Seepage runs along Cottonwood Wash (table 5) indicate that the wash has both gaining and losing reaches upstream from Towaoc but mainly losing reaches downstream from Towaoc. Measurements were made in May 1982 after the peak of the "snowmelt" runoff and in April 1983 prior to the peak of the "snowmelt" runoff.

During the snowmelt period, the northeast and northwest forks are mostly gaining reaches, accumulating the inflow from 10 identified springs (table 3), snowmelt, and diffuse seepage from talus and block rubble. Contributions from the two forks are about equal. However, losses to channel alluvium occur downstream from spring 4 in the northeast fork and downstream from spring 5 (Juana Lopez Spring) in the northwest fork (fig. 9). Most of the channel loss occurs in the northeast fork. During most of the year, flow in the northeast and northwest forks usually occurs only in the vicinity of springs 2, 4, 5, 7, 8, 10, and 11.

From the confluence of the northeast and northwest forks to the vicinity of spring 12, streamflow in the north fork of Cottonwood Wash steadily increases during the spring months, as seeps and springs issuing from pediment and channel alluvium enter the wash. During the rest of the year, this fork usually is dry. Most of the flow in this fork is diverted to Cottonwood Reservoir, but there is considerable leakage from the reservoir back to the wash through the alluvium and occasional overflow from the reservoir.

The flow at the Cottonwood Reservoir intake ditch on May 27, 1982, was 1.33 ft^3/s (597 gal/min). All but 0.05 ft^3/s (22 gal/min) was diverted to the reservoir. There is no spillway or aqueduct from the reservoir, but from May 27 to August 18, 1982, storage in the reservoir decreased from 3.24 to 0 acre-ft, mostly because of evapotranspiration and leakage.

Between spring 12 and Towaoc, streamflow in Cottonwood Wash seeps into the channel alluvium before reaching Towaoc Reservoir during most years. In years with larger than normal winter precipitation, however, some streamflow reaches Towaoc Reservoir. During April 4-7, 1983, a discharge of 7.17 ft^3/s (3,220 gal/min) was measured in the wash at spring 12. Sixty-nine percent of this discharge seeped into the channel alluvium between spring 12 and the Towaoc Reservoir; the remaining 2.22 ft^3/s (996 gal/min) entered the reservoir. All water in this reservoir evaporates or seeps into the underlying pediment alluvium.

Table 5.--*Streamflow gains and losses in Cottonwood Wash, May 26-27, 1982*

[Negative sign indicates outflow. Inflows and outflows other than numbered springs, artesian-well discharge, and reservoir diversion are calculated from streamflows]

Inflow or outflow	Discharge: Cubic feet per second	Discharge: Gallons per minute	Cumulative Discharge: Measuring site	Cumulative Discharge: Cubic feet per second	Cumulative Discharge: Gallons per minute
Spring 1	0.012	5.2			
Diffuse seepage	.12	52			
			a	0.13	57
Spring 2	.076	34			
Spring 10	.115	52			
Spring 11	.115	52			
			b	.44	197
Spring 4	.025	11			
				.46	208
Channel loss	-.22	-96			
TOTAL NORTHEAST FORK			c	.25	112
Spring 3	.076	34			
Diffuse seepage	.064	29			
			d	.14	63
Spring 5	.29	131			
				.43	194
Channel loss	-.26	-118			
			e	.17	76
Spring 6	.027	12			
Spring 7	.027	12			
Spring 8	.013	5.8			
Channel return	.23	103			
TOTAL NORTHWEST FORK			f	.47	211
TOTAL NE AND NW FORKS				.72	323
Channel return	.25	112			
Diffuse seepage	.36	162			
			g	1.33	597
Cottonwood Reservoir diversion	-1.28	-574			
				.05	23
Channel loss	-.04	-18			
			h	.01	5
Reservoir leakage	.49	220			
			i	.50	225
Spring 12	.058	26			
				.56	251
Towaoc aqueduct	-.058	-26			
Channel loss	-.50	-225			
TOTAL NORTH FORK			j	0	0
			k	0	0

Table 5.--*Streamflow gains and losses in Cottonwood Wash, May 26-27, 1982*--Continued

Inflow or outflow	Discharge		Cumulative Discharge		
	Cubic feet per second	Gallons per minute	Measuring site	Cubic feet per second	Gallons per minute
Spring 13	0.0045	2.0			
TOTAL MIDDLE FORK			l	0.0045	2.0
Artesian well P	.0033	1.5			
				.0078	3.5
Channel loss	-.0078	-3.5			
			m	0	0
Spring 15	.0033	1.5			
				.0033	1.5
Channel loss	-.0033	-1.5			
TOTAL MAIN FORK			n	0	0

Virtually no flow occurs from Towaoc to the mouth of the wash. All of the flow from three small springs and an artesian well seeps into the channel alluvium a short distance downstream from each source. Most of the runoff from rainfall and snowmelt also seeps into the channel alluvium; however, some of it occasionally discharges into Navajo Wash. From May 1982 to April 1983, surface runoff at the mouth of Cottonwood Wash was observed only once during six visits to the watershed. On April 7, 1983, the measured discharge at the mouth of the wash was 1.28 ft^3/s (574 gal/min). This runoff originated in the middle fork of the wash from melting of a larger than normal snowpack. Measured discharge at the confluence of the middle and north forks (site l) was 1.42 ft^3/s (637 gal/min), but channel losses occurred from the confluence to the mouth.

Annual surface runoff from Cottonwood Wash estimated by the Precipitation-Runoff Modeling System ranged from 82 to 189 acre-ft/yr during the 1980-82 water years (table 6), averaging 123 acre-ft/yr (0.17 ft/s). The estimated maximum daily discharge during this period was 7.19 ft^3/s (3,230 gal/min); no flow occurred on most days. During the 1982 water year, the estimated maximum daily discharge was 5.73 ft^3/s (2,570 gal/min). The estimated annual surface runoff for the 1982 water year was 98 acre-ft based on the climatic record from October to June and empirical estimates of the runoff in July, August, and September.

Table 6.--*Estimated daily discharge in Cottonwood Wash at Navajo Wash, water years 1980-82*

[Discharges are in cubic feet per second. A dash=no data]

WATER YEAR 1980

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	0	0	0	0	0	0	0.21	0	0	0	0	0
2	0	0	0	0	0	0	.88	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	.14	0	0	2.57	0	0	0	0	0	0
5	0	0	.06	0	0	.22	0	0	0	0	0	0
6	0	0	0	0	0	0	0	.05	0	0	0	.20
7	0	.07	0	0	0	2.27	0	0	0	.02	0	.20
8	0	.69	0	0	0	.72	0	1.20	0	.05	0	.02
9	0	1.58	0	0.58	0	0	0	.06	0	0	0	.39
10	0	0	0	3.72	0	0	0	0	0	0	0	.25
11	0	0	0	.68	0	.16	0	1.43	0	0	0	1.92
12	0	0	0	.91	0	2.50	0	1.60	0	0	0	0
13	0	0	0	1.02	0	0	0	0	0	0	.05	0
14	0	0	0	.33	.81	0	0	0	0	0	.29	0
15	0	0	0	2.24	4.63	0	0	.06	0	0	0	0
16	0	0	0	0	1.62	0	0	.77	0	0	0	0
17	0	0	0	1.09	.65	.15	0	0	0	0	0	0
18	0	0	0	.29	2.04	0	0	0	0	0	0	0
19	0	0	0	.90	4.77	0	0	0	0	0	0	0
20	0	.43	0	5.69	5.27	0	0	0	0	0	0	0
21	4.45	0	0	1.73	2.19	0	.16	0	0	0	0	0
22	.27	0	1.73	0	7.19	0	.13	0	0	0	0	0
23	0	0	.41	0	0	.85	0	0	0	0	0	.05
24	0	0	0	0	.06	1.00	0	0	0	0	1.15	0
25	0	0	0	0	0	.53	0	0	0	0	.33	0
26	0	0	0	0	0	0	0	0	0	0	.14	0
27	0	0	2.58	0	0	.53	0	0	0	0	0	0
28	0	0	.36	0	0	2.19	0	0	0	0	0	0
29	2.33	0	0	1.63	0	0	0	0	0	0	0	0
30	0	0	0	4.66		0	0	0	0	.18	0	0
31	0		0	0		0		0		0	0	
Total	7.05	2.78	5.28	25.47	29.23	13.70	1.39	5.17	0	0.26	2.01	2.98

Annual: Mean, 0.26; Maximum, 7.19; Minimum, 0;
Total: 95.40 cubic feet per second-days (189 acre-feet).

Table 6.--*Estimated daily discharge in Cottonwood Wash at Navajo Wash, water years 1980-82*--Continued

WATER YEAR 1981

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	0	0	0	0	0	0	0	0	2.21	0.94	0	0.08
2	0	0	0	0	0	0	0	0	0	1.02	0	0
3	0	0	0	0	0	1.20	0	0.73	.95	0	0	.13
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	.16
6	0	0	2.82	0	0	.51	0	.05	0	0	0	.84
7	0	0	.27	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0.84	0	0	0	0	0	.05	.21
10	0	0	0	0	.55	0	0	0	0	0	.13	0
11	0	0	0	0	0	1.31	0	0	0	0	.13	1.80
12	0	0	0	0	0	.04	0	0	0	.16	2.16	0
13	.07	.51	0	0	0	0	0	0	0	1.90	.15	0
14	.02	.54	0	0	0	.32	0	0	0	.03	0	0
15	1.26	0	0	0	0	.19	.06	.02	0	.06	0	0
16	.58	0	0	0	0	0	0	2.17	0	.78	0	0
17	0	0	0	0	0	0	0	1.62	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	1.84	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	.97	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	1.57	0	0	0	0	0	0	0	0	0	.14
25	0	0	0	0	1.10	0	0	0	0	0	0	.11
26	0	0	0	0	0	0	0	0	.13	0	0	0
27	1.15	0	0	0	0	0	0	0	.07	.10	0	0
28	0	0	0	0	0	.83	0	1.01	0	0	0	0
29	0	0	0	.12		.18	0	.27	.05	0	.13	0
30	0	0	0	0		0	0	.37	0	0	0	0
31	0		0	.92		0		.28		0	.13	
Total	3.09	2.63	3.10	1.05	2.50	5.55	1.90	6.53	3.42	4.99	2.88	3.47

Annual: Mean, 0.11; maximum, 2.82; Minimum, 0.
Total: 41.10 cubic feet per second-days (81.5 acre-feet).

Table 6.--*Estimated daily discharge in Cottonwood Wash at Navajo Wash, water years 1980-82*--Continued

WATER YEAR 1982

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	0	0	0	0.49	0	0	0	0	0	--	--	--
2	.20	0	0	1.01	0	1.47	.17	.05	0	--	--	--
3	5.73	0	0	.05	0	.58	0	0	0	--	--	--
4	.20	0	0	0	0	.14	0	.02	0	--	--	--
5	.12	0	0	0	0	0	0	2.01	0	--	--	--
6	.07	0	0	.60	0	0	0	.38	0	--	--	--
7	0	.12	0	.08	0	0	0	0	0	--	--	--
8	0	0	0	0	0	0	0	0	0	--	--	--
9	0	0	0	0	0	0	0	0	0	--	--	--
10	0	0	0	0	0	0	0	0	0	--	--	--
11	0	0	1.17	0	1.76	.04	0	0	0	--	--	--
12	.10	0	0	.25	.02	.30	0	.31	0	--	--	--
13	.37	0	0	0	0	0	0	2.58	0	--	--	--
14	0	0	0	0	0	0	0	0	0	--	--	--
15	.14	0	0	0	.05	.08	0	0	0	--	--	--
16	1.27	0	0	0	0	1.09	0	0	0	--	--	--
17	0	0	0	0	1.43	0	0	0	0	--	--	--
18	0	0	0	0	0	0	0	0	0	--	--	--
19	0	0	0	0	0	.79	0	0	0	--	--	--
20	0	0	0	0	0	0	.03	0	0	--	--	--
21	0	0	0	0	0	0		0	.02	--	--	--
22	0	0	.42	1.73	0	0	0	0	0	--	--	--
23	0	0	0	0	0	0	.03	0	0	--	--	--
24	0	0	0	0	0	0	.16	0	0	--	--	--
25	0	0	0	0	2.94	0	.12	0	0	--	--	--
26	0	0	0	0	0	0	0	0	0	--	--	--
27	0	0	0	0	0	3.02	0	0	0	--	--	--
28	0	.66	0	0	0	.08	0	0	0	--	--	--
29	0	1.60	0	0		.51	0	0	0	--	--	--
30	0	.63	0	.25		.91	0	0	0	--	--	--
31	0		1.10	0		.59		0		--	--	
Total	8.20	3.03	2.70	4.48	6.20	9.59	0.51	5.35	0.02	--	--	--

Annual: Mean, 0.14; Maximum, 5.73; Minimum, 0.
Total[1]: 49.4 cubic feet per second-days (95 acre-feet).

[1]Includes estimates of discharge in July, August, and September, based on estimated precipitation and drainage area.

GROUND WATER

Ground water is available from several unconsolidated surficial deposits and from confined bedrock aquifers. The principal bedrock aquifers listed in table 1 in descending order are the Dakota Sandstone-Burro Canyon Formation (sandstone and conglomerate), Junction Creek Sandstone, Entrada Sandstone, Glen Canyon Group (sandstones), De Chelly Sandstone-Cutler Formation (sandstone and siltstone), and the Leadville Limestone-Ouray Formation (limestone and dolomite). Interbedded confining layers predominantly consist of mudstone, siltstone, quartzite, evaporites, or fine-grained dolomite. In some confining layers, sandstone or limestone beds, such as the Juana Lopez Member of the Mancos Shale or the Salt Wash Sandstone Member of the Morrison Formation, yield water locally. Hydraulic conductivities of several formations within or near the study area are listed in table 7.

As of 1983, there were only two operating wells in or near the watershed (table 8). Well E reportedly yields water from alluvium at a rate of 0.5 gal/min. Well P, a flowing artesian well of unknown depth and geologic source, yields water with a specific conductance of 980 to 1,180 μS/cm (microsiemens per centimeter at 25° Celsius) to a stock tank at a rate of 1.0 to 1.5 gal/min. Ten other wells formerly supplied water for residents or livestock.

Surficial deposits, which include talus, block rubble, colluvium, pediment alluvium, and channel alluvium, are connected hydraulically and form a contiguous aquifer. Ground water is recharged by rainfall, snowmelt, and seasonal leakage from Cottonwood Reservoir and Cottonwood Wash. Springs issuing from talus, block rubble, and colluvium may yield more than 100 gal/min, but yields fluctuate substantially from season to season and from year to year, and some springs cease flowing during late summer and fall. The older pediment alluvium is dissected and generally drained but may yield substantial quantities of water derived from snowmelt during the spring and early summer months. The younger pediment and channel alluvium yield small, seasonally variable quantities of water (usually less than 10 gal/min) to wells and springs.

The quantity of recoverable water contained in the surficial deposits is difficult to ascertain because of sparse sub-surface information. During most of the year, the channel alluvium and older pediment alluvium probably contain water only near the base, where downward percolation is restricted by the Mancos Shale. Talus, block rubble, and colluvium contain quite variable quantities of stored water, depending on the texture of the material and the seasonal availability of the water.

The quantity of recoverable water in the younger pediment alluvium can be estimated from the surface area, saturated thickness, and estimated specific yield of the deposit. The surface area (fig. 2) is 2.17 mi^2 (1,390 acres). The average saturated thickness was about 17.5 ft during the 1982 and 1983 water years (fig. 10), but it probably ranges from 10 to 20 ft seasonally and annually. Ground-water levels generally are highest after the snowmelt season and lowest before the onset of precipitation in the fall or winter.

Table 7.--*Hydraulic conductivity in Cottonwood Wash watershed and adjacent areas*

[Values are in feet per day. Sources of data include Lohman (1965), Irwin (1966), Woodward-Clyde Consultants (1982), Teller and Chafin (1984), and unpublished petroleum industry files. Dashes are shown in minimum and maximum columns when only one test result was available for a geologic unit.]

Geologic unit	Hydraulic conductivity				Remarks
	Number of tests	Minimum	Maximum	Median	
Younger pediment alluvium---	1	---	---	50	Determined in well A.
Mancos Shale----------------	4	0.00032	0.028	0.0036	Determined in petroleum test holes, northwestern Colorado.
Dakota Sandstone and Burro Canyon Formation.	3	.00027	.0077	.00056	Determined in petroleum test holes, northwestern Colorado and near Moab, Utah.
Morrison Formation----------	4	.018	.061	.035	Determined near Grand Junction, Colorado, and near Moab, Utah.
San Rafael and Glen Canyon Groups.	3	.0054	.027	.0066	Determined in wells L, M, and N.
Cutler Formation------------	4	.0034	.012	.0035	Determined in petroleum test holes, southwestern Colorado.
Hermosa Formation-----------	21	.000054	.38	.024	Determined in petroleum test holes, southwestern Colorado. Tests were in petroleum-bearing layers that are atypical of unit.
Leadville Limestone and Ouray Formation.	10	.0013	.14	.0073	Determined in petroleum test holes, southwestern Colorado.

Table 8.--*Records of selected wells and test holes*

[Location: System of numbering spring, well, and test-hole locations is illustrated in figure 13 in Supplemental Information section at back of report. Casing diameter: Variable diameter holes indicated by slash between successive diameters. Abbreviations: ft=feet; ft/d=feet per day; gal/min=gallons per minute. Dashes indicate no data]

Site designation	Location number	Year completed	Depth of well (feet)	Casing diameter (inches)	Open interval (feet)	Yield (gallons per minute)	Altitude of land surface (feet)	Date water level measured	Water level (feet)	Use of well in 1982	Remarks
						Wells completed in alluvium					
A	$NB03301707UDDA_1$	1954	65.8	8/7	32-45	10.3 (pumped)	5,885	2/07/54	31.1	Observation	Well B-15 of Irwin (1966). Hydraulic conductivity is 49.5 ft/d. Water-yielding gravel at 32 ft.
								5/25/82	24.0		
								8/17/82	24.9		
								10/24/82	25.8		
								1/10/83	25.3		
								4/04/83	26.3		
B	$NB03301707UDDA_2$	----	98	6	-----	3 (reported)	5,880	2/07/54	33.5	Destroyed	Well B-14 of Irwin (1966).
C	NB03301708UCCB	1982	36	4	16-36	----	5,881	11/16/82	21.4	Observation	Pumped dry in 30 seconds at 16.7 gal/min.
								12/15/82	21.2		
								1/10/83	22.0		
								2/10/83	20.6		
								3/16/83	20.1		
								4/04/83	17.4		
D	NB03301718UDDD	1956	29.5	------	-----	1 (bailed)	5,820			Destroyed	Well B-4 of Irwin (1966). Reported water level at 25 ft.
E	NB03301729UADD	1978	36.4	8	-----	0.5 (reported)	5,460	5/25/82	12.3	Domestic	Pump installed 10/82. Alluvium penetrated by well reportedly is sand.
								8/17/82	13.0		
								11/16/82	13.0		
								1/10/83	12.3		
								4/07/83	11.4		
F	NB03301729UCCA	1982	34	4	14-34	----	5,440	11/16/82	16.1	Observation	
								12/15/82	16.0		
								1/10/83	16.2		
								2/10/83	16.3		
								3/16/83	16.1		
								4/07/83	15.2		
G	NB03301825UABC	1956	77.0	6	25-40	2 (pumping)	5,690	9/03/56	30.1	Abandoned	Well B-2 of Irwin (1966).
H	NB03401705DBD	1953	35	-----	-----	----	6,380	--------	----	Destroyed	Test hole 2 of Powell (1954).
I	NB03401705DCA	1953	50	-----	-----	----	6,370	--------	----	Destroyed	Test hole 3 of Powell (1954).

Table 8.--*Records of selected wells and test holes*--Continued

Site designation	Location number	Year completed	Depth of well (feet)	Casing diameter (inches)	Open interval (feet)	Yield (gallons per minute)	Altitude of land surface (feet)	Date water level measured	Water level (feet)	Use of well in 1982	Remarks
						Wells completed in bedrock					
J	NB03301707UDBA	1931	1,750	8/6	1,073-1,750	17 (reported)	5,922	2/09/54	60.8	Abandoned	Well B-13 of Irwin (1966) completed in Junction Creek, Entrada, and Navajo Sandstones.
K	NB03301707UDDC	1954	960	8/6	804-936	9 (bailed)	5,885	4/21/54	625	Abandoned	Well B-16 of Irwin (1966). Completed in Morrison Formation.
L	NB03301708UCBB	1957	1,825	7/5/54	-----	20 (operating)	5,917	11/10/57	349.5	Abandoned	Well B-19 of Irwin (1966). Completed in Junction Creek, Entrada, and Navajo Sandstones.
M	NB03301717UCCA	1957	2,002	7/5	1,460-2,000	20 (operating)	5,739	9/27/57	277.6	Abandoned	Well B-18 of Irwin (1966). Completed in Junction Creek, Entrada, and Navajo Sandstones.
N	NB03301718UABA	1957	1,769	12/8/6	1,264-1,769	40 (operating)	5,877	2/15/57	371.0	Abandoned	Well B-17 of Irwin (1966). Completed in Junction Creek, Entrada, and Navajo Sandstones.
O	NB03301718UCCA	1958	528	6	335-528	5 (operating)	5,880	7/17/58	73.3	Abandoned	Well B-10 of Irwin (1966). Completed in Dakota Sandstone and Burro Canyon Formation.
P	NB03301720UCCC	----	-----	------	-----	------	5,556	5/25/82	flowing	Stock	Average discharge in 1982-83 was 1.4 gal/min.

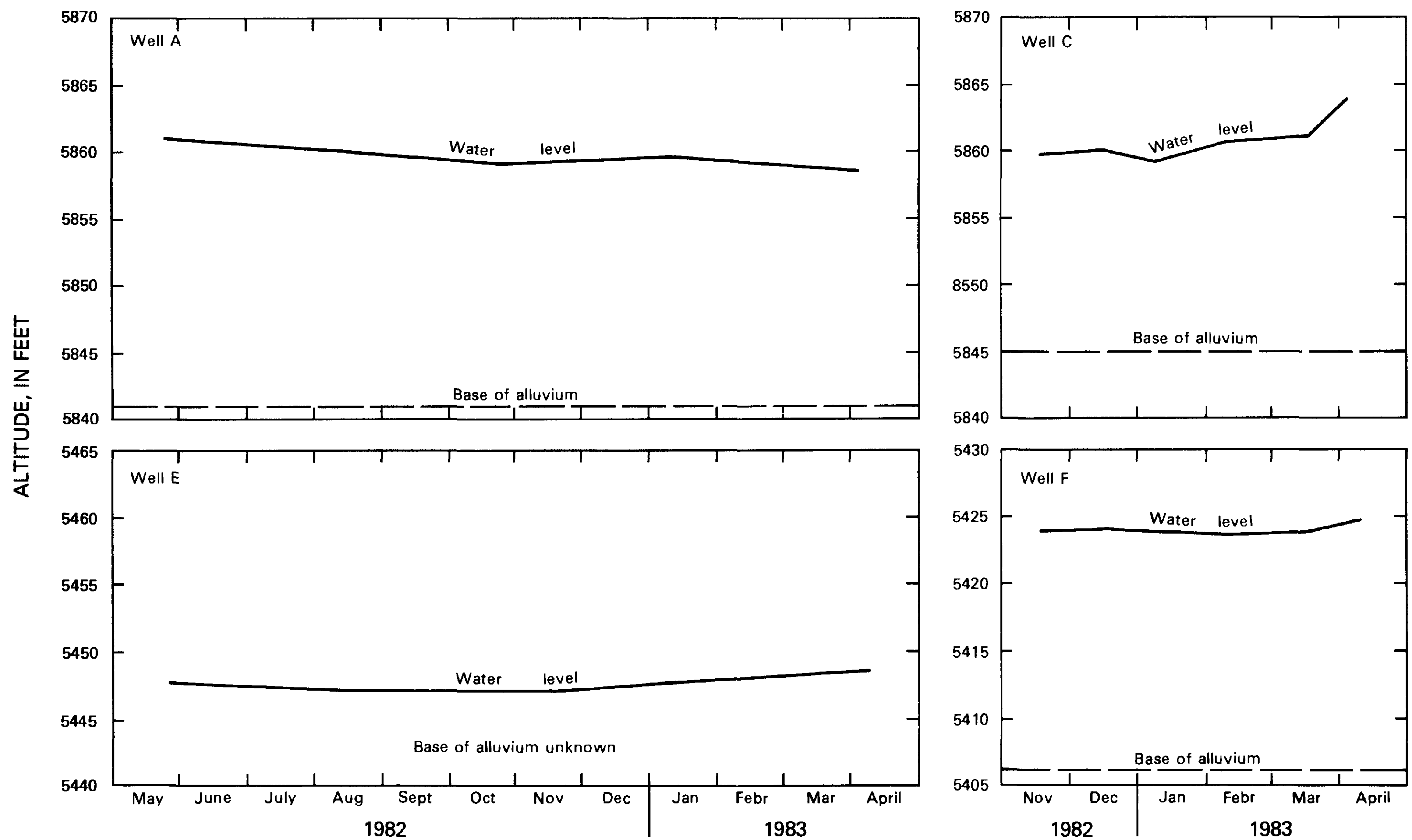


Figure 10.--Recorded water levels in alluvium, 1982-83.

The specific yield of an aquifer is the volume of water released under the influence of gravity, expressed as a fraction of the total volume of material in the aquifer. Although specific yield data are not available for the study area, the specific yield of the younger pediment alluvium can be estimated from the material comprising the deposit and from specific-yield values of alluvium on the nearby Navajo Indian Reservation. The younger pediment alluvium consists of 44 percent sand, 28 percent clay, and 27 percent gravel in geologic logs of wells and test holes (included in the Supplemental Information section at the back of this report). Specific yields of alluvium on the Navajo Reservation range from 0.005 to 0.25 (Cooley and others, 1969, p. 46). If the smallest of these values is assumed to be characteristic of clay, the largest characteristic of gravel, and an intermediate value of 0.15 characteristic of sand, then the compositionally weighted specific yield of the younger pediment alluvium is estimated to be about 0.14.

Based on the preceding information, the estimated volume of recoverable water in the younger pediment alluvium in the 1982 water year was 3,400 acre-ft. In other years, it probably ranges from 2,000 to 4,000 acre-ft.

Water in the younger pediment alluvium is more easily recoverable from gravel layers than from sand. Upstream from Towaoc, the gravel is uniformly distributed, but, downstream, it occurs in buried channels. Wells not penetrating these channels have very small yields (Powell, 1954, p. 7-8). As an example, well A, which penetrates a buried gravel channel, yielded 10.3 gal/min and had 3.5 ft of drawdown during a 6.7-hour pumping period (Powell, 1954, p. 11-12). However, well C, 125 ft from well A and drilled mostly through sand, ran dry after about 30 seconds of pumping at a rate of 16.7 gal/min. Well A was used to provide a municipal water supply for many years, whereas well C probably would not produce a usable sustained yield.

Some of the water that seeps into channel alluvium eventually leaves the watershed as underflow from Cottonwood Wash and adjacent arroyos. Streamflow gains to Navajo Wash adjacent to the Cottonwood Wash watershed are derived almost entirely from underflow.

Measured streamflows in Navajo Wash (table 9) indicate that most underflow occurs from April to June when Cottonwood Wash and hydraulically connected arroyos are all contributing underflow. Underflow from July to December apparently is derived solely from Cottonwood Wash. Underflow apparently is inhibited during the winter months by sub-freezing temperatures. The estimated cumulative underflow to Navajo Wash in the 1982 water year, based on averaged quarterly estimates, was 740 acre-ft.

Sleeping Ute Mountain is a recharge area for bedrock formations. Recharge occurs from precipitation falling upon exposed rock and from seepage through overlying alluvium. In both cases, infiltration primarily is controlled by the hydraulic conductivities of the uppermost bedrock formations; these include the Tertiary igneous rocks, Mancos Shale, Dakota Sandstone, Burro Canyon Formation, and Morrison Formation.

The igneous rocks crop out over about 2,570 acres. A reasonable estimate of hydraulic conductivity is 10^{-6} ft/d (Freeze and Cherry, 1979, p. 29).

Table 9.--*Streamflow gains and losses in Navajo Wash*

[Discharges in cubic feet per second]

Tributary		Navajo Wash	
Inflow or outflow	Discharge	Measurement site	Discharge
		May 18, 1982	
		Upstream from Towoac road------	19.6
Arroyo underflow and bank seepage.	1.1		
		Upstream from Cottonwood Wash--	20.7
Cottonwood Wash underflow---	1.2		
		Downstream from Cottonwood Wash	21.9
Channel loss----------------	3.1		
		Upstream from U.S. 160---------	18.8
		August 17, 1982	
		Upstream from Cottonwood Wash--	18.7
Cottonwood Wash underflow---	.7		
		Downstream from Cottonwood Wash	19.4
		October 7-13, 1982	
		Upstream from Towoac road------	21.5
Channel loss----------------	.3		
		Upstream from Cottonwood Wash--	21.2
Cottonwood Wash underflow---	1.1		
		Downstream from Cottonwood Wash	22.3
		January 10-13, 1983	
		Upstream from Towoac road------	1.94
Channel loss----------------	.36		
		Upstream from Cottonwood Wash--	1.58
Channel loss----------------	.24		
		Downstream from Cottonwood Wash	1.34

Estimated annual recharge, calculated by multiplying outcrop area, hydraulic conductivity, and hydraulic gradient is less than 1 acre-ft. The hydraulic gradient is assumed to be 1.0 for these estimates of vertical movement.

Mancos Shale crops out over about 2,170 acres and underlies about 3,770 acres of pediment alluvium. The minimum hydraulic conductivity indicated in table 9, 0.0003 ft/d, probably approximates the rate of vertical seepage (see Bredehoeft and others, 1983). Estimated annual recharge based on area of occurrence and hydraulic conductivity, is 650 acre-ft.

The Dakota Sandstone, Burro Canyon Formation, and Morrison Formation crop out over about 1,790 acres. The minimum hydraulic conductivity for the Morrison Formation listed in table 9 seems too large for a vertical seepage rate and might prove to be smaller with more extensive testing. The minimum hydraulic conductivity listed for the Dakota Sandstone and Burro Canyon Formation in table 9 may approximate the rate of vertical seepage through sandstone layers of all three formations. Based on this assumption and the aggregate outcrop area, annual recharge to the three formations is estimated as 200 acre-ft.

Combined annual recharge to the five uppermost bedrock units in the area is estimated as 850 acre-ft. The actual quantity of annual recharge probably is somewhat less, because (1) Rates of infiltration decrease as surface layers become saturated; (2) moisture from precipitation may not always be available for recharge; and (3) site conditions, such as soil or vegetative cover, may interfere with the recharge process.

WATER QUALITY

The chemical quality of water in the Cottonwood Wash watershed (table 10) generally reflects the composition of the aquifers. The concentration of minerals is small in water from block rubble and talus, which are composed largely of igneous rock fragments that resist chemical weathering. The concentration of minerals is fairly large in water from the Mancos Shale, which is composed of clay and salt minerals that easily weather. The concentration of minerals in water from the alluvium, which is composed of igneous rock fragments and weathered Mancos Shale, is moderate to large. The water in wells is less mineralized than in springs. Surface water in Cottonwood Wash, which, for most of the year, is derived from springs and infrequent storms, changes in quality as springs enter the wash, generally becoming more mineralized in a downstream direction.

Water in the study area contains either calcium and bicarbonate or calcium and sulfate as the dominant ions (fig. 11). Water issuing as springs from block rubble, talus, and older pediment alluvium is a calcium bicarbonate type. During June 1982, dissolved-solids concentrations in the water from springs 2, 3, 4, 5, and 6 ranged from 217 to 485 mg/L and averaged 376 mg/L. By October 1982, two of these springs, 3 and 6, had ceased flowing; in the three remaining springs, discharges were 59 to 98 percent smaller than in June, and the dissolved-solids concentrations ranged from 303 to 621 mg/L, averaging 484 mg/L.

Water issuing as springs from Mancos Shale, colluvium, younger pediment alluvium, and channel alluvium generally is a calcium sulfate type, but it may be a calcium bicarbonate type at times. In June 1982, dissolved-solids concentrations in the water from springs 1, 7, 8, 12, 13, and 16 ranged from 539 to 2,540 mg/L and averaged 1,250 mg/L. By October 1982, three of these springs, 1, 13, and 16, had ceased flowing; in two of the remaining springs, 8 and 12, discharges were 87 and 98 percent smaller than in June. The dissolved-solids concentration in the water from spring 8 was 1,130 mg/L; in the water from spring 12, it was 656 mg/L.

Table 10.--*Chemical analyses of*

[Location: See figure 13 in Supplemental Information section at back of report for illustration
Qc=colluvium derived from Mancos Shale; Qp=pediment alluvium; Km=Mancos shale. Concentrations
Concentration of bicarbonate calculated as alkalinity divided by 0.8202. Dash=no data; N/A=not

Site designation	Location number	Geologic source	Date of sample	Temperature (degrees Celsius)	pH	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Calcium	Magnesium	Potassium
									Surface
c	Northeast fork upstream from northwest fork.	N/A	06/09/82	7.5	8.6	640	110	18	0.9
f	Northwest fork upstream from northeast fork.	N/A	06/09/82	8.0	8.6	510	82	14	.8
g	North fork upstream from Cottonwood Reservoir.	N/A	06/08/82	12.5	8.1	740	120	18	.8
i	North fork upstream from Spring 12.	N/A	06/08/82	14.5	7.7	790	130	20	1.9
									Springs
1	NB03501824CCC	Qc	06/09/82	23.0	8.2	1,200	160	62	1.2
2	NB03501825BBC	Qt	06/09/82	9.5	7.5	710	110	22	1.0
			10/12/82	10.0	7.8	800	140	19	1.3
3	NB03501827DAA	Qt	06/10/82	8.0	7.4	360	53	7.4	1.4
4	NB03501836BAD	Qt	06/09/82	11.0	7.4	700	120	18	1.5
			10/12/82	12.0	7.4	909	160	24	1.3
5	NB03501835ACC	Qt	06/09/82	9.0	7.2	410	60	8.5	.7
			10/12/82	8.5	6.6	460	83	11	.8
6	NB03501835CCC	Qt	06/10/82	8.0	7.1	732	120	20	.4
7	NB03401802DAB	Qc	06/10/82	14.0	8.1	740	130	22	1.0
8	NB03401801CBC	Qc,Km	06/10/82	13.5	7.5	1,860	340	55	8.8
			10/12/82	8.5	7.2	1,300	270	44	5.1
9	NB03401706BAA	Qp	10/03/51	----	---	833	155	16	---
12	NB03401705DCA	Qp	06/08/82	11.5	7.6	1,110	200	34	.5
			10/12/82	12.5	7.1	937	160	27	.4
13	NB03301717UCCB	Qp	05/25/60	13.5	7.7	1,080	126	54	---
			06/08/82	19.0	7.7	3,000	440	140	12
16	NB03301729UADC	Qp	10/03/51	16.5	---	1,050	141	39	---
			06/08/82	13.5	7.7	1,620	180	52	.8
									Ground water
A	NB03301707UDDA1	Qp	03/12/54	14.5	---	761	122	20	---
B	NB03301707UDDA2	Qp	11/05/53	----	---	871	100	48	---
G	NB03301825UABC	Qp	12/06/56	13.5	7.9	---	65	12	---

[1]Sodium+potassium, calculated by subtraction of all other analyzed constituents from dissolved

water in Cottonwood Wash watershed

of system of numbering spring and well locations. Geologic source: Qt=talus and block rubble;
of all constituents in milligrams per liter unless otherwise specified; µg/L=micrograms per liter.
applicable]

Sodium + potassium	Sodium	Bicarbonate	Sulfate	Chloride	Fluoride	Nitrogen	Silica	Iron (µg/L)	Manganese (µg/L)	Selenium (µg/L)	Barium (µg/L)	Hardness	Dissolved solids (residue at 180 degrees Celsius)
water													
N/A	15	244	160	11	0.2	<0.1	16	<3	3	8	32	350	451
N/A	16	227	100	4.3	.2	<.1	17	<3	<1	3	33	260	346
N/A	17	284	170	6.1	3.0	.14	19	28	3	6	41	370	513
N/A	19	279	200	8.2	.3	.15	17	41	20	5	53	410	535
N/A	31	236	540	6.1	.4	1.0	10	<3	<1	13	67	660	932
N/A	14	260	170	6.8	.2	.76	16	7	1	6	31	370	471
N/A	15	304	180	5.3	.2	<.1	16	<3	7	2	58	430	527
N/A	7.7	174	38	1.2	.2	<.1	22	<3	2	2	26	160	217
N/A	17	291	160	5.1	.3	<.1	19	160	10	8	31	370	485
N/A	20	379	200	6.1	.2	<.1	22	4	6	6	40	500	621
N/A	9.3	200	37	2.1	.2	<.1	19	<3	1	3	22	180	235
N/A	11	274	40	1.9	.2	<.1	20	<3	3	2	26	250	303
N/A	19	311	130	5.9	.2	.44	21	12	3	4	38	380	472
N/A	16	232	230	6.8	.2	<.1	19	12	18	4	43	420	539
N/A	57	371	790	16	.3	3.4	15	<3	5	13	68	1,100	1,480
N/A	38	410	540	12	.2	.86	18	8	4	8	47	860	1,130
[1]12	-----	385	151	4.0	.1	.1	18	---	--	--	--	452	546
N/A	27	319	400	17	.2	<.1	22	<3	<1	11	61	640	858
N/A	25	366	230	8.6	.2	<.1	24	<3	<1	5	49	510	656
[1]42	-----	300	345	22	.2	.3	25	130	120	--	--	537	812
N/A	170	377	1,500	77	.4	<.1	21	50	30	1	37	1,700	2,540
[1]39	-----	224	372	18	.3	.6	27	---	--	--	--	512	747
N/A	97	206	630	66	.3	.26	25	<3	85	12	28	660	1,150
from wells													
[1]21	-----	292	169	10	.2	2.3	22	---	--	--	--	386	510
[1]21	-----	302	223	8	.2	1.2	20	---	--	--	--	447	570
[1]45	-----	237	113	5	--	---	--	---	--	--	--	210	465

solids.

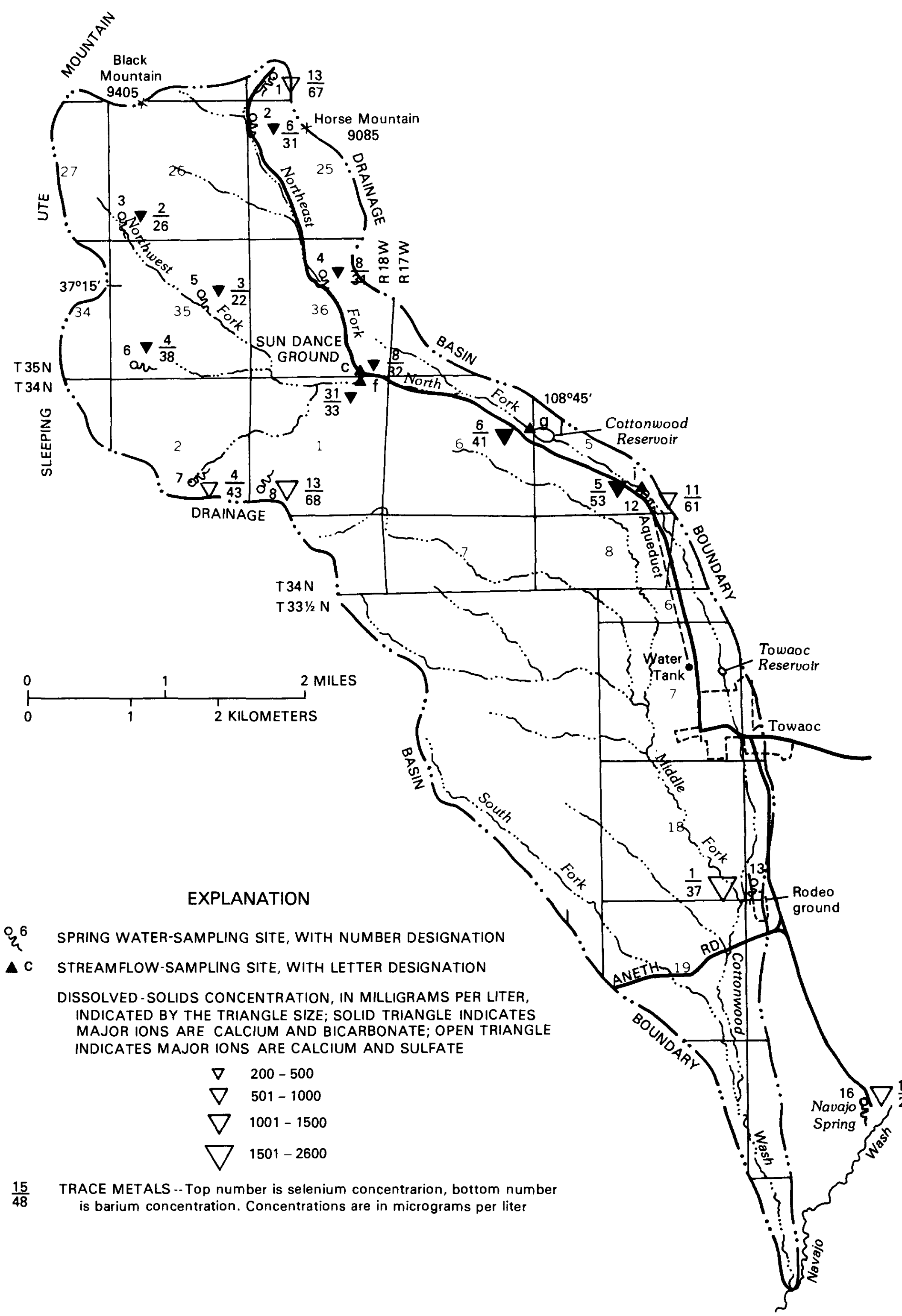


Figure 11.--Chemical constituents and concentration of dissolved solids in water from springs and streamflow, June 8-9, 1982.

No samples of water were collected from wells during this study. Water samples collected between 1953 and 1956 from wells A, B, and G, which were completed in the younger pediment alluvium, contained calcium and bicarbonate as the dominant ions and dissolved-solids concentrations of 465 to 570 mg/L.

Surface water sampled at four sites in June 1982 was a calcium bicarbonate type. The dissolved-solids concentration of this water increased in a downstream direction from 346 to 535 mg/L.

Certain major ions are present in concentrations that exceed drinking water standards established by the U.S. Environmental Protection Agency (1977a, 1977b). Dissolved-solids concentrations commonly exceed 500 mg/L in water issuing as springs from Mancos Shale, colluvium, younger pediment alluvium, and channel alluvium. Sulfate concentrations in this water ranged from 230 to 1,500 mg/L during the 1982 water year. Dissolved-solids concentrations in excess of 500 mg/L may impart a mineral taste to water, and sulfate concentrations in excess of 250 mg/L can have a laxative effect.

Hardness is essentially the sum of the calcium and magnesium ions expressed as an equivalent concentration of calcium carbonate. Hardness in water issuing as springs from block rubble and talus ranged from 160 to 370 mg/L in June 1982 and from 250 to 500 mg/L in October 1982. Hardness in water issuing as springs from Mancos Shale, colluvium, and alluvium ranged from 420 to 1,700 mg/L in June 1982 and from 510 to 860 mg/L in October 1982. Hardness in surface water sampled in June 1982 increased in a downstream direction from 260 to 410 mg/L. According to criteria in Hem (1970, p. 225), all of the water in the study area is hard and can encrust pipes and impede sudsing.

Selenium is present locally in water at concentrations that exceed the limit of 10 μg/L (micrograms per liter) recommended by the U.S. Environmental Protection Agency (1977a, 1977b). Chronic exposure to selenium by ingestion or inhalation can lead to mental disorders, dermatitis, or gastrointestinal disturbance (National Research Council, 1977, p. 354). In June 1982, four of the six springs issuing from Mancos Shale, colluvium, younger pediment alluvium, and channel alluvium that were sampled (1, 8, 12, and 16) contained water with selenium concentrations of 11 to 13 μg/L (table 10). However, concentrations of selenium in water from these springs decreased to safe levels of 2 to 8 μg/L by October 1982. In contrast, selenium concentrations in the water issuing as springs from block rubble and talus and in streamflow never exceeded 8 μg/L during the 1982 water year.

Although barium concentrations in waters of the Cottonwood Wash watershed are relatively large, they do not approach the limit of 1,000 μg/L recommended by the U.S. Environmental Protection Agency (1977a, 1977b). Barium concentrations in spring water ranged from 22 to 68 μg/L in June 1982, averaging 51 μg/L in water from the Mancos Shale, colluvium, younger pediment alluvium, and channel alluvium and 30 μg/L in water from block rubble and talus (table 10). Concurrently, barium concentrations in water flowing in Cottonwood Wash increased downstream from 32 to 53 μg/L. As discharges decreased during the summer months, barium concentrations increased in the water issuing as springs from block rubble and talus and decreased in the water issuing as springs from Mancos Shale, colluvium, and younger pediment alluvium. The source of barium in the water is probably the igneous rocks of Sleeping Ute Mountain, which contain far more barium than world-wide averages for rocks of similar origin and composition (Ekren and Houser, 1965, p. 39-40).

Other minor and trace elements analyzed include fluoride, nitrogen, iron, and manganese. During 1982, fluoride generally was present in concentrations of less than 0.4 mg/L, but the water in Cottonwood Wash at site g, upstream from Cottonwood Reservoir, contained 3.0 mg/L. Nitrogen generally was present in concentrations of less than 0.2 mg/L, but water issuing as springs from Mancos Shale, colluvium, and the younger pediment alluvium contained as much as 3.4 mg/L. Iron was present in many samples at concentrations of less than 3 μg/L, but a sample from spring 4 had an iron concentration of 160 μg/L. Manganese concentrations varied from less than 1 to 85 μg/L, averaging 13 μg/L. Fluoride and manganese locally exceeded drinking water standards recommended by the U.S. Environmental Protection Agency (1977a, 1977b). Fluoride concentrations greater than 1.9 mg/L may mottle teeth, and manganese concentrations in excess of 50 μg/L may stain laundry.

Very little bacteriological contamination was found in the Cottonwood Wash watershed. Samples of spring water and streamflow were analyzed for fecal-coliform bacteria, an indicator of disease-transmitting organisms. Fecal-coliform counts of more than 200 colonies per 100 mL (milliliters) of water indicate a significant risk of infection by water-borne pathogens. At four surface-water sites, c, f, g, and i, fecal-coliform counts in June 1982 ranged from 1 to 12 colonies per 100 mL of water. At three spring sites, 2, 5, and 12, concurrent fecal-coliform counts ranged from less than 1 to 6 colonies per 100 mL of water. By October 1982, there was no runoff in Cottonwood Wash other than springflow, and fecal-coliform counts at all spring sites visited were less than 1 colony per 100 mL of water.

CONSUMPTIVE USE

Most of the water consumed by residents is transported into the watershed by ditch from the Dolores River (fig. 1). The Ute Mountain Ute Indian Reservation is entitled to 200 shares of Dolores River water (about 1,614,000 gal/d), but the Reservation is the last user on the ditch and does not always receive its allotted share. If the full allotment were delivered daily, the cumulative annual inflow would be 1,810 acre-ft.

The water from the Dolores River is first stored in a 50-million-gallon earthen reservoir near the point where the ditch enters the reservation. The water then is pumped to a 1,015,000-gal concrete storage tank at Towaoc, from which it is distributed to residents by pipelines. The capacity of the earthen reservoir has been decreasing steadily because of silt accumulation. As a result, flow in the ditch can exceed the storage capacity of the reservoir at times. When this happens, the ditch water cannot be diverted and is released into Navajo Wash.

Water supplies from the Dolores River are augmented by flow from spring 12, which during 1982 and 1983 supplied an infiltration gallery with 4,750 to 61,900 gal/d (an average of 19 acre-ft/yr). Water from the infiltration gallery is transported to the storage tank at Towaoc through an aqueduct. In many years, however, the water from spring 12 is not used and is released into Cottonwood Wash.

Other sources of water have been developed locally. Since October 1982, well E has supplied water from pediment alluvium to a house owned by Kenneth Bancroft. Prior to installing a pump on the well, the owner of the house diverted water from spring 16 (Navajo Spring). Both the well and the spring are in the Navajo Wash watershed, but the water supplying them discharges from Cottonwood Wash through contiguous pediment alluvium. Many of the springs in the watershed are developed with ponds, pipes, or troughs for onsite livestock or human use; these include springs 2, 5, 6, 8, 9, and 17. A small quantity of water in Cottonwood Reservoir is consumed onsite by livestock or hauled to Towaoc for domestic use.

According to tribal spokesmen, the 1,200 residents of Towaoc consumed about 175 gal/d of water per person in 1982. The total daily consumption of water, thus, was about 210,000 gal. Less than 1 percent of the water originating in the watershed was consumed.

WATER BUDGET

The movement of water in a particular area may be expressed as a water budget, in which an accounting is made of all water entering and leaving the area. The water budget, in equation form is:

$$\text{Inflow} = \text{Outflow} \pm \text{Change in storage}$$

where inflow includes surface water, precipitation, and ground water;
outflow includes consumptive use, surface runoff, underflow, evapotranspiration, and recharge to bedrock; and
change in storage includes changes in surface-reservoir storage and alluvial storage.

A generalized water budget for the Cottonwood Wash watershed during the 1982 water year is shown in figure 12. Values shown may differ slightly from references in the text because of rounding. The change in alluvial storage was calculated as the residual of all other components. If the indicated change was restricted to the younger pediment alluvium, a rise of 1.5 ft in the water table between the 1981 and 1982 water years would be required.

WATER-RESOURCES DEVELOPMENT

Augmentation of municipal water supplies available in 1983 can be accomplished in several ways. These include: (1) Development of one or more additional springs; (2) utilization of water stored in Cottonwood Reservoir; (3) enlargement of the presently used infiltration gallery; and (4) drilling of one or more wells to pump ground water stored in alluvium.

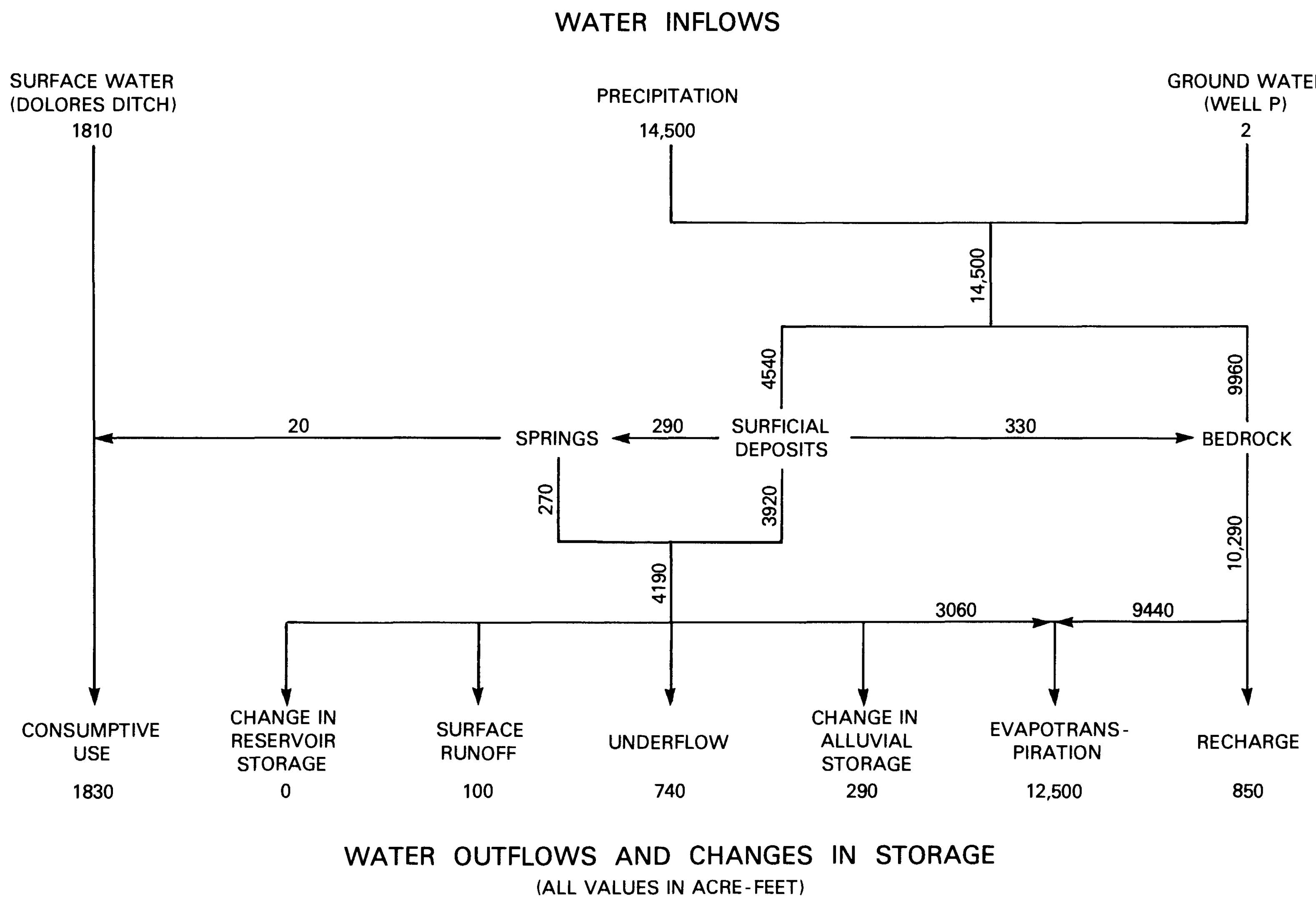


Figure 12.--Generalized water budget for 1982 water year.

The development of spring 5 (Juana Lopez Spring) is likely to produce a substantial supply of water during the spring and early summer. This spring has a larger discharge during the "snowmelt" runoff period than any other spring in the watershed, including spring 12, which is currently used as a municipal water supply. The water from spring 5 complies with recommended drinking-water standards for dissolved solids, sulfate, selenium, and fecal-coliform bacteria. In contrast, the water from spring 12 exceeds the drinking-water standards for selenium and sulfate during the "snowmelt" runoff period and exceeds recommended limits for dissolved solids throughout the year. Damming the wash downstream from spring 5 not only would contain all of the spring's discharge but also would make use of runoff from snowmelt, rainfall, and springs upstream from spring 5. A delivery system from the site of spring 5 to Towaoc would have to be devised.

Installation of delivery systems for the water from springs 2 and 4 would provide additional supplies. Spring 4 has the most consistent year-round discharge; spring 2 has a smaller perennial discharge. Both springs 2 and 4 yield water comparable in quality to spring 5.

Using water stored in Cottonwood Reservoir would avoid the expense of developing springs in the upper watershed but would provide less water to Towaoc. If a pipeline were installed from Cottonwood Reservoir to Towaoc, a large amount of water would be available as a municipal supply during the spring months. However, during the rest of the year, Cottonwood Reservoir would provide little or no water. In contrast, developing springs in the upper watershed would provide a year-round water supply. A considerable amount of water originating in the upper watershed never reaches Cottonwood Reservoir because of in-channel seepage to alluvium and evapotranspiration. Transporting spring water from the point of origin would eliminate these losses.

Additional supplies might be obtained by enlargement of the infiltration gallery supplied by spring 12 to divert unused water flowing from the pediment alluvium into Cottonwood Wash during the "snowmelt" runoff period. Spring 12 has water of marginally acceptable quality but has a larger discharge during the summer months and is closer to Towaoc than any other potentially developable spring in the watershed. However, because the quantity of water discharging from pediment alluvium apparently depends, at least partly, on reservoir storage upstream, additional springflow created by expansion of the infiltration gallery probably would be minimal in years with low precipitation and at times of the year when the reservoir contains little or no water. Continued use of the infiltration gallery at its present size could augment supplies created by developing springs in the upper watershed. However, yields from the infiltration gallery would decrease if other springs were developed upstream because water from those springs no longer would be seeping into the alluvium.

One or more wells could be completed in alluvium to capture water currently leaving the area as underflow or seeping to bedrock. Such wells need to be placed where the aquifer is thickest and the water has the best quality.

The largest sustained yields are likely from gravel layers, which have the most uniform distribution upstream from Towaoc. Downstream from Towaoc, gravel occurs mostly in buried channels, and ground water contains unacceptable concentrations of dissolved solids, sulfate, and selenium. However, any water obtained from wells developed in the alluvium would be poorer in quality than water from most springs in the upper watershed.

Regardless of how municipal supplies are augmented, current storage facilities at Towaoc are inadequate to store additional water. More storage facilities will be necessary if additional municipal supplies are developed.

SUMMARY AND CONCLUSIONS

Anticipated water shortages for residents of Towaoc, Colorado, on the Ute Mountain Ute Indian Reservation, may be alleviated partly by development of shallow ground water and seasonally available surface water in the Cottonwood Wash watershed. The average annual precipitation influx to the 16-mi^2 watershed is estimated to be 14,600 acre-ft. The estimated precipitation influx in the 1982 water year was 14,500 acre-ft.

Flow in the wash is mostly ephemeral, but springs issuing from block rubble, talus, alluvium, colluvium, and Mancos Shale sustain perennial flow in their vicinity. Springs have their greatest distribution and discharge from April to June, when the ground is saturated with snowmelt. Discharges are at their minimum from September to November, when many springs cease flowing. Total estimated spring flow in the 1982 water year was 290 acre-ft.

Most surface runoff occurs upstream from Towaoc. Reservoirs limit streamflow downstream from Towaoc during most of the year. Estimated surface runoff from the Cottonwood Wash watershed in the 1982 water year was about 100 acre-ft.

Eighty-six percent of incident precipitation in the 1982 water year was consumed by evapotranspiration. Residents of the area used less than 1 percent of the available water originating in the watershed. An estimated 740 acre-ft of water left the area as underflow into Navajo Wash, and 850 acre-ft of water seeped into bedrock.

Pediment alluvium in the lower watershed contains an estimated 2,000 to 4,000 acre-ft of recoverable water. This alluvium contained 3,400 acre-ft of recoverable water in the 1982 water year, about 290 acre-ft more than in the previous water year.

The water from shallow sources generally is not very mineralized. Most of this water is a calcium bicarbonate type containing less than 600 mg/L of dissolved solids. Water seeping from alluvium in the lower watershed and from Mancos Shale and colluvium throughout the area, however, may contain levels of sulfate, selenium, and dissolved solids that are unacceptable for domestic consumption.

Anticipated water shortages can be relieved by augmenting current water supplies with water from the study area. Development alternatives include: (1) Transporting water from springs in the upper watershed; (2) using water stored in Cottonwood Reservoir during the spring and early summer; (3) enlarging the presently used infiltration gallery; and (4) drilling wells into pediment alluvium upstream from Towaoc. Springs 2, 4, and 5 have the best chemical quality and year-round flow of all potential water resources.

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SUPPLEMENTAL INFORMATION

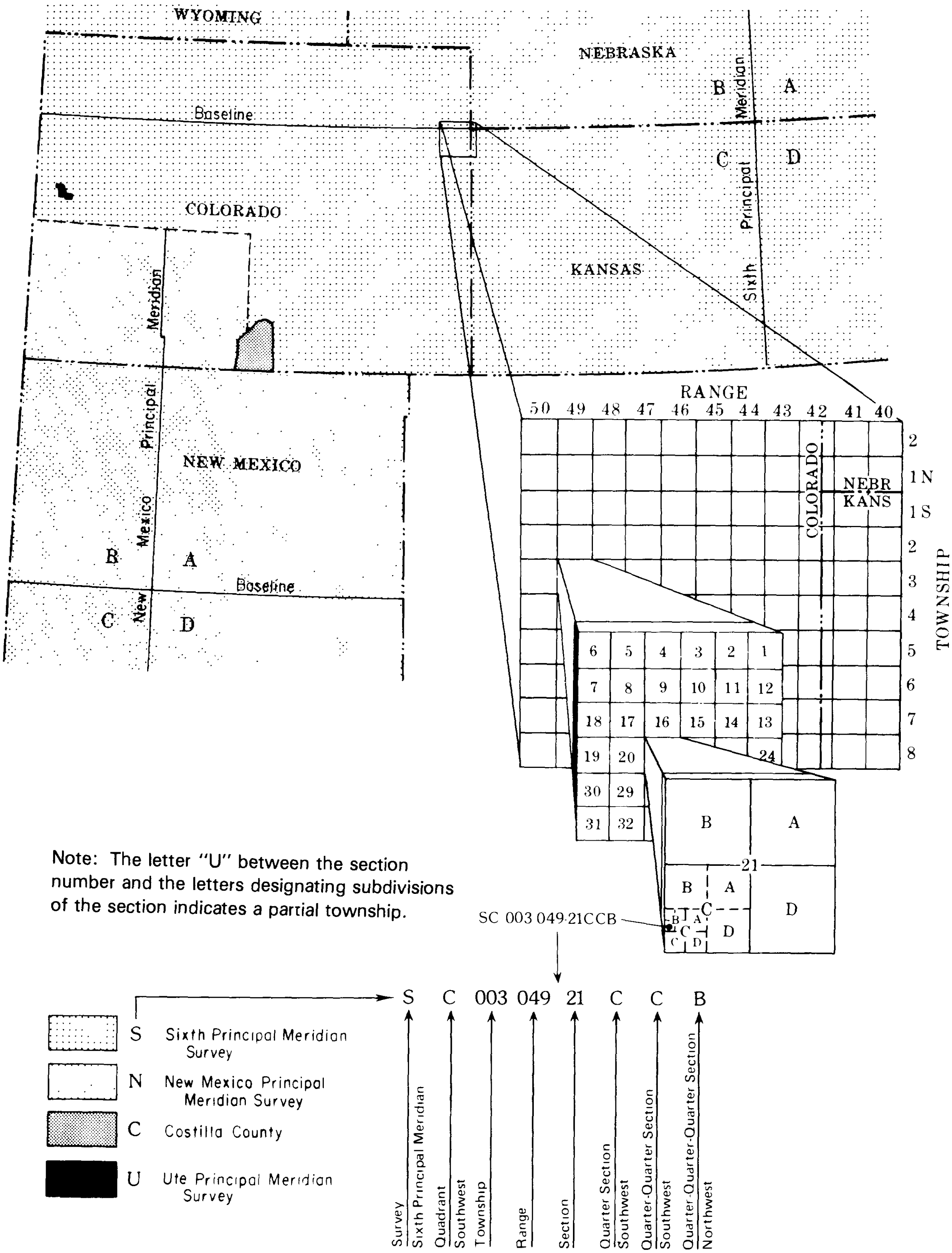

Figure 13.--System of numbering springs, wells, and test holes.

Geologic Logs of Wells and Test Holes in the Cottonwood Wash Watershed

Description	Thickness (feet)	Depth below land surface (feet)
Well A, NB03301707UDDA, altitude 5,885 feet, abandoned		
Quaternary:		
Alluvium:		
Clay, silty to sandy, brown to gray, with fine to very coarse gravel at 6.5 feet.	9	9
Sand, very fine to very coarse, with fine to coarse gravel; interbedded with yellowish soft clay.	23	32
Sand and gravel, very fine to very coarse, containing a few large boulders (contains water).	12	44
Cretaceous:		
Mancos Shale:		
Shale, dark blue, silty, firm-------------------	21.8	65.8
Well C, NB03301708UCCB, altitude 5,881 feet, abandoned		
Quaternary:		
Alluvium:		
Silt, sandy, brown, minor caliche---------------	1.5	1.5
Clay, gray--------------------------------------	2.5	4
Sand, fine, brownish yellow, with scattered gravel.	6	10
Sand, fine, brownish yellow, gravelly; contains gravel layer at base.	3	13
Sand, fine, brownish yellow, with scattered gravel.	7	20
Sand, fine, brownish yellow, with gravelly sand and gravel layers.	16	36
Cretaceous:		
Mancos Shale:		
Shale, dark gray--------------------------------	12	48
Well F, NB03301729UCCA, altitude 5,440 feet, abandoned		
Quaternary:		
Alluvium:		
Sand, fine, pinkish brown, with very scattered gravel.	11	11
Sand, fine, pinkish brown, with clay seams------	3	14
Sand--	8	22
Gravel--	1	23
Sand--	3	26
Gravel--	3	29
Sand--	4	33
Clay, gray--------------------------------------	1	34
Cretaceous:		
Mancos Shale:		
Shale, gray, fissile----------------------------	4	38

Geologic Logs of Wells and Test Holes in the Cottonwood Wash Watershed--Continued

Description	Thick-ness (feet)	Depth below land surface (feet)
Well G, NB03301825UABC, altitude 5,690, abandoned		
Quaternary:		
Alluvium:		
Gravel, sand, and clay	10	10
Gravel, clay, and a few boulders	10	20
Gravel and clay, with sand	20	40
Cretaceous:		
Mancos Shale:		
Shale, medium to dark gray	37	77
Well H, NB03401705DBD, altitude 6,380 feet, destroyed		
Quaternary:		
Alluvium:		
Soil, red	4	4
Soil, gravelly, red	12	16
Gravel, fine, red	4	20
Gravel, fine, buff (contains water)	13	33
Cretaceous:		
Mancos Shale:		
Shale, dark blue	2	35
Well I, NB03303401705DCA, altitude 6,370 feet, destroyed		
Quaternary:		
Alluvium:		
Soil	2	2
Gravel	1	3
Boulders	5	8
Gravel	23	31
Cretaceous:		
Mancos Shale:		
Shale	19	50
Well J, NB03301707UDBA, altitude 5,922 feet, abondoned		
Quaternary:		
Alluvium:		
Dirt, brown	9	9
Clay or silt, brown	18	27
Sediment, brown	18	45
Boulders and gravel (water)	3	48
Sediment, black	12	60
Boulders and gravel (water)	5	65
Cretaceous:		
Mancos Shale	155	220
Dakota Sandstone and Burro Canyon Formation	190	410

Geologic Logs of Wells and Test Holes in the Cottonwood Wash Watershed--Continued

Description	Thickness (feet)	Depth below land surface (feet)
Well J, NB03301707UDBA, altitude 5,922 feet, abondoned--Continued		
Jurassic:		
Morrison Formation and Junction Creek Sandstone-----	840	1,250
Jurassic and Triassic (?):		
Summerville Formation, Entrada Sandstone, Navajo Sandstone.	500	1,750
Well K, NB03301707UDDC, altitude 5,885 feet, abandoned		
Quaternary:		
Alluvium:		
Clay, brown, silty to sandy, with gravel-------	24	24
Clay, yellow, silty to sandy, with gravel------	3	27
Sand, fine to coarse, with gravel and clay-----	13	40
Sand, fine to coarse, with clay and shale fragments (water at about 40 feet).	2	42
Cretaceous:		
Mancos Shale---------------------------------------	231	273
Dakota Sandstone-----------------------------------	88	361
Burro Canyon Formation-----------------------------	117	478
Jurassic:		
Morrison Formation:		
Brushy Basin Shale Member----------------------	327	805
Salt Wash Sandstone Member---------------------	155	960
Well L, NB03301708UCCB, altitude 5,917 feet, abandoned		
Quaternary:		
Alluvium:		
Sand, fine to coarse, gravelly-----------------	30	30
Sand, gravelly, with clay, silt, and boulders--	20	50
Cretaceous:		
Mancos Shale---------------------------------------	270	320
Dakota Sandstone and Burro Canyon Formation---------	210	530
Jurassic:		
Morrison Formation---------------------------------	610	1,140
Junction Creek Sandstone---------------------------	240	1,380
Summerville Formation------------------------------	130	1,510
Entrada Sandstone----------------------------------	90	1,600
Jurassic and Triassic:		
Navajo and Wingate (?) Sandstones------------------	225	1,825

Geologic Logs of Wells and Test Holes in the Cottonwood Wash Watershed--Continued

Description	Thickness (feet)	Depth below land surface (feet)
Well N, NB03301718UABA, altitude 5,877 feet, abandoned		
Quaternary:		
Alluvium:		
Soil and clay, olive	20	20
Clay, gravelly, silty, medium-gray	20	40
Cretaceous:		
Mancos Shale	220	260
Dakota Sandstone and Burro Canyon Formation	230	490
Jurassic:		
Morrison Formation	610	1,100
Junction Creek Sandstone	260	1,360
Summerville Formation	150	1,510
Entrada Sandstone	70	1,580
Jurassic and Triassic (?):		
Navajo Sandstone	189	1,769

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