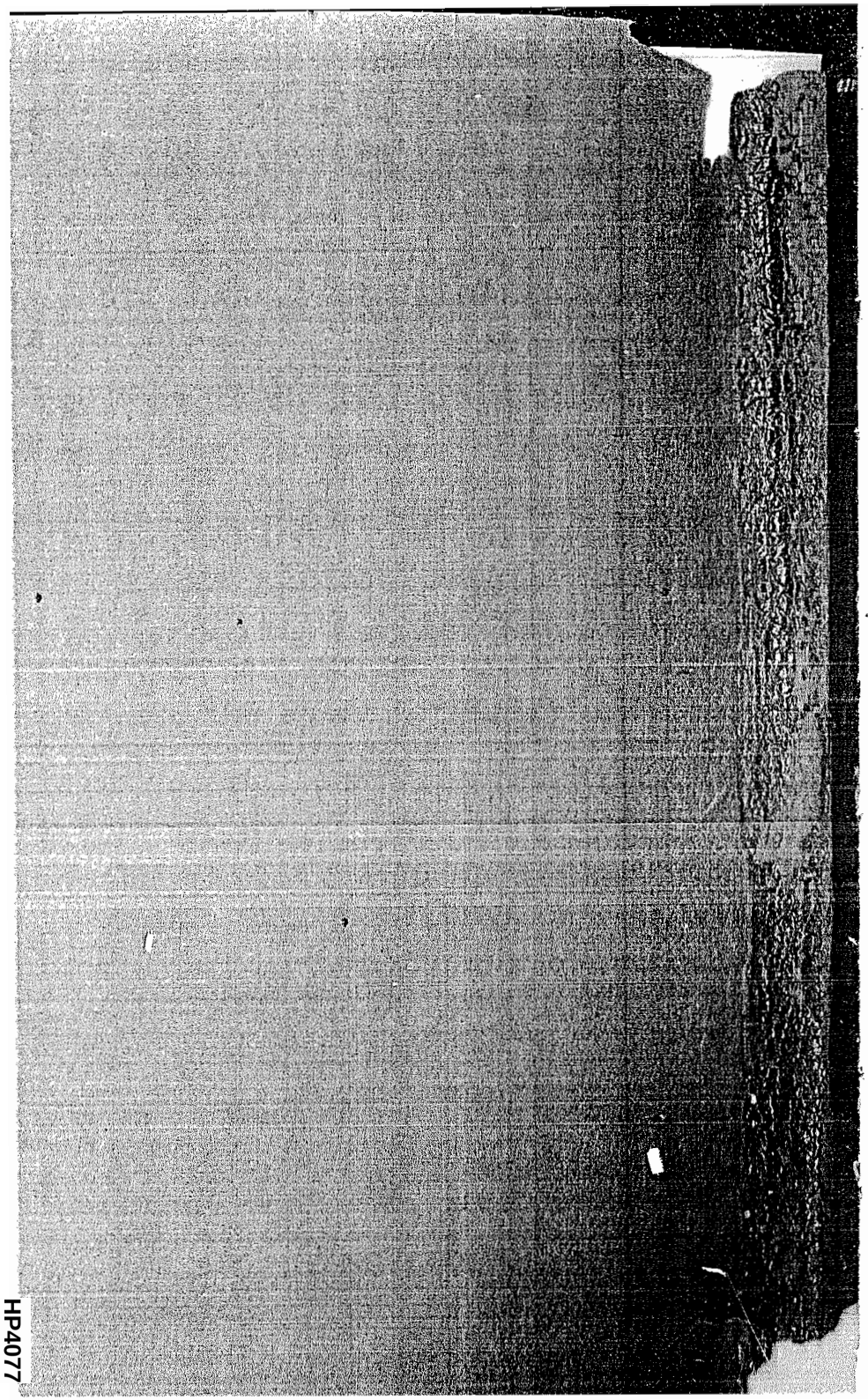

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DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

Water-Supply Paper 380

THE NAVAJO COUNTRY

A GEOGRAPHIC AND HYDROGRAPHIC RECONNAISSANCE OF PARTS OF ARIZONA, NEW MEXICO, AND UTAH

BY

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WASHINGTON
GOVERNMENT PRINTING OFFICE
1916

brought the land to its present position with respect to the sea. At one stage during late Tertiary time (Pliocene) erosion became dominant and reduced parts of the area to a peneplain. The gradient of the streams was later increased by a regional uplift, which enabled them greatly to reduce the area occupied by Mesozoic and Cenozoic strata. Other uplifts, amounting to 3,000 to 4,000 feet, still further augmented the power of the streams and enabled them to cut the canyons which form so conspicuous a feature of Navajo topography.

PART II. SURFACE WATERS.

STREAMS.

MASTER STREAMS OF THE REGION.

Three large rivers—the Colorado, the San Juan, and the Little Colorado, with its tributary, the Puerco—mark the borders of the Navajo country. The Colorado, the master stream of the plateau province, eventually receives the surface water from the entire region except for an insignificant amount carried to the Rio Grande. From the mouth of the San Juan to Echo Cliffs the Colorado flows between the brightly colored walls of Glen Canyon; below Lee Ferry it occupies the still more profound Marble Canyon. Throughout its course in the Navajo country it flows as a powerful stream whose moderate grade is interrupted by few rapids.

The San Juan is a perennial stream. Along its upper course it receives the waters of vigorous tributaries which have their sources in the San Juan and La Plata mountains. Within the 90-mile stretch of winding channel from Bluff to Colorado River it receives no continuous supply of importance, but maintains a depth of 3 to 5 feet even in the dry season.[1] Measurements of flow taken at Farmington, N. Mex., gave the following results:

Monthly discharge, in second-feet, of San Juan River at Farmington, N. Mex.[a]

Month.	Maximum.	Minimum.	Mean.
1904.			
June (12 days)	1,300	780	1,030
July	1,578	20	375
August	4,980	1,450	2,627
September	8,625	400	1,375
October	20,000	2,625	5,935
November	1,695	630	1,087
December	780	90	348
1905.			
January	338	40	242
February	2,582	230	682
March	3,410	780	1,625
April	7,460	1,085	4,290
May	19,100	4,635	10,110
June	24,800	10,960	18,270
July	8,240	2,180	3,604
August	3,740	840	1,747
September	4,870	1,180	1,673
October	4,635	1,180	1,690
November	2,708	1,085	1,306
December	1,300	840	1,084
1906.			
May			11,700
June 4			9,090
June 8 (station discontinued)			12,800

[a] U. S. Geol. Survey Water-Supply Paper 133, pp. 180-183, 1904; Water-Supply Paper 175, p. 134, 1906; Water-Supply Paper 211, p. 101, 1908.

[1] The course of the San Juan below Bluff, as shown on published maps, is correct only with respect to general direction.

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The Puerco-Little Colorado is an intermittent stream. From its source on the Continental Divide in New Mexico to Holbrook in Arizona it is marked at low water by a dry bed interrupted by stretches of stream rarely exceeding a mile in length. I have been informed that during parts of certain years no flowing water is to be found in the Puerco from Gallup westward to its mouth. At Holbrook it joins the upper Little Colorado, a perennial stream from the White Mountains. Between Hardy and Winslow the Little Colorado receives the waters of Chevelon Fork and Clear Creek,[1] tributaries from the central Arizona highlands which give to the Little Colorado its perennial character throughout the 33-mile course from Holbrook to Winslow and make this section, including the settlements at Holbrook, St. Joseph, and Winslow the only part of the Puerco-Little Colorado Valley that has attained commercial importance. From Winslow to Colorado River, a distance of over 100 miles, the flow of the Little Colorado is seasonal, and during years of normal precipitation it reaches a stage where no running water is to be found except on the floor of the canyon near the junction with its master stream. The quantity of water it carries at Holbrook, where its continuous flow is largest, is given in the following table:

Monthly discharge, in second-feet, of Little Colorado River at Holbrook, Ariz.[a]

Month.	Maximum.	Minimum.	Mean.
1905.			
March (15 days)	1,190	718	863
April	2,075	504	915
May (25 days)	1,055	145	353
June	145	44	82.6
July	488	5	67.9
August	1,200	33	163
September	1,760	15	302
October	220	19	50.7
November	20,180	30	1,159
December	325	45	113
1906.			
January	1,330	165	452
February	325	73	170
March	3,540	66	621
April	987	100	245
May	150	5	54
June	5	3	4.1
July	140	3	24.9
August	275	15	71.5
September	600	4	68.7
October	250	5	26.6
November	63	4	11.3
December	890	25	181
1907.			
January	1,000	90	276
February	380	73	176
March	2,100	115	444
April	573	290	401

[a] U. S. Geol. Survey Water-Supply Paper 133, pp. 180–183, 1904; Water-Supply Paper 175, p. 134, 1906; Water-Supply Paper 211, p. 101, 1908.

[1] In 1906 the maximum flow of Chevelon Fork near Winslow was 3,870 second-feet (in March), the minimum was 0.25 second-foot (September to November), and the mean for the year was 110 second-feet; from June 3 to December 31 of the same year the maximum discharge of Clear Creek near Winslow was 2,245 second-feet (in December), and the minimum was 3 second-feet (in August): U. S. Geol. Survey Water-Supply Paper 211, pp. 117, 119, 1908. The mean discharge of Clear Creek for the period has been computed as 52.9 second-feet.

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THROUGH-FLOWING STREAMS.

The Colorado, the San Juan, and the Little Colorado are the only streams of the Navajo country that carry water from areas beyond the limits of the reservation. Within the reservation the drainage from 9,897 square miles, an area which contains no perennial through-flowing streams, is directed toward the Puerco and Little Colorado. The Colorado receives the waters from Navajo Creek, a perennial stream through the 54 miles of its canyoned course and carrying at low stages nearly 2 second-feet of water. Several of the short, deep canyons entering the Colorado from the Rainbow Plateau contain minute streams; Oak Creek and Nasja furnish perennial supplies; and a rill of clear, pure water finds its way down Bridge Canyon, passing beneath the Rainbow Arch. The San Juan is the goal of Junction, Cha, and Desha creeks, which drain the northern slopes of Navajo Mountain and maintain a flow of 10 to 100 gallons a minute, even during the season when precipitation is lacking and evaporation assumes excessive proportions.

The San Juan also receives perennial supplies from Piute Creek, which drains a narrow strip of land immediately adjoining its canyoned valley. (See Pl. XVIII, *A*, p. 69.) In July, 1910, the estimated flow of Piute Creek 6 miles above its mouth was 0.20 second-foot, and the average of two estimates made in June, 1913, at points near the head of the canyon was 0.15 second-foot. Nokai, Copper, and Moonlight canyons hold trickling rills of water which find their way into the San Juan. Gypsum Creek, which drains the eastern half of Monument Valley, is rarely dry. The longest stream of perennial flow which finds its way to the borders of the reservation is Tyende Creek. This stream emerges from the many-branched Laguna Canyon at Marsh Pass, winds its way through the hogback rim of Monument Valley, traverses Sahotsoidbeazhe Canyon, and enters Chinle Valley, which it follows to the San Juan. At Marsh Pass the discharge during the dry season is about 1.70 second-feet, which is the largest flow noted at any point along the stream during the months of June and July, 1909, 1910, and 1913.

INTERMITTENT STREAMS.

Within the limits of the reservation are a number of intermittent streams that occupy well-defined drainage channels but reach their master streams only during the rainy season. Three of these streams, the Moenkopi, Black Creek, and the Pueblo Colorado, are tributary to the Puerco and Little Colorado.

MOENKOPI CREEK.

Of all the tributaries of the lower Little Colorado the Moenkopi (Hopi, running water) flows most continuously and responds most

readily to seasonal precipitation. Topographically it is separable into three sections of subequal length. The upper third (25 miles) is intrenched in the Cretaceous strata of Black Mesa, forming a narrow, steep-walled canyon, joined by tributaries that occupy valleys of similar shape. The terraces and flats on the canyon floor are a few acres in extent and are discontinuous. The stream is fed during the dry season by a few springs and seeps distributed along its course, which supply an interrupted flow of 10 to 30 gallons a minute. At Blue Canyon (Navajo, Bokogo dotklish) the intermittent stream emerges from the dark-gray rocks of the upper canyon and enters the second part of its course, where it is confined between low walls of brilliantly colored sandstones of Jurassic age. During this stretch of 30 miles, between Blue Canyon and the cliffs west of Tuba, the stream is alternately buried by sand and brought to the surface by ledges of rock. Patches of alluvium, 10 to 50 acres in extent, flanking the stream channel, from time to time have been reclaimed by irrigation, occasionally at considerable expense. Near Moenkopi village the underflow of the stream is brought to the surface by exposed rock ledges and is supplemented by supplies from Reservoir Canyon and from numerous springs of the vicinity. The combined flow of water from these sources amounts, even in dry seasons, to perhaps 5 second-feet and exceeds that at any other locality on the reservation. Fortunately wide valley flats below Moenkopi village are favorably situated for irrigation, and agriculture has here reached a higher stage of development than elsewhere in the Navajo country. The Spanish pioneers found at Moenkopi cultivated fields of corn and of cotton, and the Mormon settlers of the Tuba oasis used these same fields for corn, wheat, oats, and alfalfa. Under the direction of the Indian Office, Hopi, Navajo, and white men now work side by side in cultivating this garden spot surrounded by an inhospitable desert.

The lower part of the Moenkopi wanders for 20 miles through the Painted Desert to join the canyon of the Little Colorado. Throughout this stretch of subdued topography its flow is intermittent and the Triassic shales which form its bed yield alkali which renders the water unpalatable.

BLACK CREEK.

From its source in Chuska Mountain to Red Lake the waters of Black Creek are in view except for stretches of a fraction of a mile. Swamps and seeps mark the sources of the various branches, and flat valley floors, susceptible of irrigation, line the stream for several miles. The run-off from 230 square miles, constituting the drainage area of this portion of Black Creek, including Red Lake, was found by the engineers of the Indian Service to be 33,328 acre-feet a year. From Red Lake to St. Michaels Black Creek occupies a shallow arroyo cut in the floor of a wide, flat-bottomed valley. Within this

distance water is present even in the dry season, as short stream stretches, interrupted by expanses of dry sandy floor. The stream is also intermittent along its course from St. Michaels to Oak Spring, below which it becomes perennial while passing through lower Black Creek Canyon, assuming once more an intermittent character in the 10-mile stretch ending at Puerco River. Two short tributaries to Black Creek, one from Buell Park, the other at St. Michaels, are perennial for a mile or so of their upper courses and reach their master stream for about six months in a year. A third tributary, Bonito Creek, rising in Quartzite Canyon, discharges at low water 0.87 second-foot,[1] and though only about 5 miles long has determined the location of Fort Defiance and made possible the irrigated fields and gardens which give to this spot its attractive features.

PUEBLO COLORADO WASH.

Nearly 1,250 square miles of the Defiance Plateau is drained by the Pueblo Colorado Wash, the upper 18 miles of which, from its source to Ganado, is a perennial stream, its discharge at low water being perhaps 2 second-feet. (See p. 110.) From Ganado to Holbrook, a distance of more than 100 miles, the stream flows only in response to showers. The terraces along the canyon in the upper portion and the wide flats below the mouth of the canyon have been cultivated by means of irrigation since the days of the cliff dwellers, and this permanent supply of water in the midst of an arid expanse has made of Ganado an important center of agricultural and commercial activity for the Navajos and the white traders.

CHINLE DRAINAGE SYSTEM.

The 4,790 square miles of the Navajo Reservation included in the Chinle drainage area comprises a region intimately associated with the life of the Navajo race and with the history of the prehistoric populations of the plateau province. Cliff ruins are found in nearly all the canyoned tributaries and traces of ancient irrigated fields are distributed far and wide through the valleys. Following the cliff dweller and the Hopi, the Navajo has occupied the favorable spots within the Chinle basin and practiced agriculture by irrigation and dry farming, making use of his knowledge of fluctuation in stream flow. The main Chinle is ephemeral in its flow from its head, 6 miles northwest of Ganado, to Chinle, a distance of 38 miles. From Chinle to the mouth of Tyende Creek the stream is ephemeral or in rare years intermittent during the dry season, with the proportion of waterless bed much in excess of flowing stretches. Below the mouth of the Tyende the flow of the Chinle is permanent, except where obstructed for short distances by accumulations of wind-

[1] Measured by Lieut. H. C. Brown, October, 1892.

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blown sand. Above the Tyende the western tributaries of the Chinle contain no perennial waters except for stretches usually less than a mile in length immediately below the springs which supply them. Some of these short streams have their origin in the Mancos shale or Chinle formation, and contain an amount of salts which renders their waters unfit for domestic uses. From the east the Chinle receives the drainage from Nazlini Canyon, Canyon de Chelly, Canyon del Muerto, Lukachukai Valley, and Walker Creek valley—channels whose upper parts, at least, are occupied by perennial streams. The Nazlini, at the exit from its canyon, has, in the dry season, a small permanent discharge, which decreases downstream until the flow becomes intermittent and finally disappears. The De Chelly is fed by small perennial streams—Whiskey Creek, Palisade Creek, and Wheatfields Creek—which rise in the Chuska Mountains and furnish Canyon de Chelly with a supply of water that is augmented by springs distributed along its course. Where measured, 6 miles from its mouth, the De Chelly, in May, 1909, had an estimated flow of 0.60 second-foot.

Canyon del Muerto is the lower part of Spruce Brook, which emerges from Tunitcha Mountain as a clear stream of pure water with a discharge exceeding 1 second-foot. Spruce Brook drops into Canyon del Muerto at Sehili,[1] and continues with more or less interrupted flow to its junction with Canyon de Chelly. Along the lower reaches of Whiskey, Palisade, and Wheatfields creeks and Spruce Brook, the flats adjoining the streams are favorably situated for irrigation. Below the mouth of Canyon del Muerto the De Chelly is normally without flowing water during the dry season.

Lukachukai Creek forms the division line between the Tunitcha and Lukachukai mountains. From its source at the crest of the mountains to the Lukachukai settlement, at the mountain base, the stream occupies a narrow wooded valley and carries even in the dry season 2 or 3 second-feet of water. For 6 or 8 miles below Lukachukai the creek maintains a perennial flow but assumes an intermittent character in the vicinity of Round Rock. Below this point the bed is normally dry for a few months each year. The colony of enterprising Navajos at Lukachukai make use of the waters of this stream to irrigate about 200 acres of corn, alfalfa, and garden lands.

The west side of Carrizo Mountain is drained by Walker Creek.[2] The upper portion of the stream, emerging from the narrow, steep-floored canyon, is called by the Navajos Chinlini (place where water comes out of a canyon); the lower middle portion is sometimes spoken of as Mexican Water, a name still retained for the store at the point where the Mormon Road of 1879 crossed the creek. Walker Creek is perennial, except for widely separated short stretches. After leaving its upper canyon at Chinlini the stream occupies a trench cut in the alluvial floor of a rock-walled canyon and in many places rests on rock. Near its junction with the Chinle the canyon is wide and the stream finds its way with more or less interrupted flow between terraces which indicate the level of a previous stage of water. The flow of Walker Creek at Chinlini as estimated is 0.70 second-foot, and I am informed that at the Mexican Water store the discharge during the summer season is about 500 gallons a minute.

In addition to the streams mentioned, two short creeks, Sheep Dip, about 12 miles north of Chinle School, and Agua Sal, entering Lukachukai Creek north of Round Rock, flow intermittently toward their master streams. The water of Sheep Dip Creek is palatable, but that of Agua Sal is said to be unfit for general use.

To the Chinle system belongs also Simpson Creek, which rises in the meadows as Washington Pass and crosses the New Mexico-Arizona boundary line near Crystal, on its way to Black Lake. The New Mexico portion of the stream is perennial and increases the attractiveness of the Washington Pass route from Fort Defiance to the San Juan. Before reaching Black Lake, however, Simpson Creek becomes intermittent and the extreme lower part flows during the dry season only in response to showers.

STREAMS TRIBUTARY TO CHUSKA VALLEY.

On the eastern flanks of the Chuska Mountains are a number of short, perennial, or intermittent streams which occupy the upper portions of canyoned valleys whose ultimate goal is the poorly defined drainage system of the Chuska Valley. The southernmost of these streams, Figueredo Creek, crossed by the Fort Defiance-Tohachi Road, is perennial for about 5 miles of its course, with a volume in dry seasons of about 30 gallons a minute. In the gap west of Chuska Peak another small stream of permanent flow was noted, and along the rim of Chuska Mountain, between Tohachi and Washington Pass, are several rills, each less than a mile long, which represent the overflow from springs. At Washington Pass a brook 2 miles or more in length discharges 20 to 25 gallons a minute through all seasons. At Toadlena is another short brook, and in the wide amphitheater south of Beautiful Mountain short streams with permanent or intermittent flows emerge from the plexus of profound canyons which gash the east face of Tunitcha Mountain. The

[1] Sehili in the Navajo language means the place where water disappears into a canyon; Chinle, the place where water emerges from a canyon mouth.

[2] In the absence of a recognized name for this stream the liberty is taken of naming it Walker Creek in honor of Capt. Walker, of Macomb's expedition of 1859. Capt. Walker crossed the stream at Ojo de Casa (Navajo: Hogan sa-a-ni, lone house in the desert). The term Gothic Wash, used on many maps, is discarded, as this name was given by Macomb to a dry canyon entering the San Juan below Bluff. See map accompanying report on the exploring expedition, etc., in 1859, under the command of Capt. J. N. Macomb, Eng. Dept., U. S. Army, Washington, 1876.

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largest of these, Tseanazti Creek, has long been used for irrigation by cliff dweller and Navajo. Toward the Chuska Valley are directed also several short intermittent streams which rise on the northwest front of Dutton Plateau. Five visited by my party were all more or less alkaline, but not to an extent which rendered them useless for watering sheep. Selukai Creek, on which is located the Government sheep dip, is usually dry except during the rainy season.

ADDITIONAL STREAMS.

In the canyons of Redrock Valley short streams of intermittent flow were found to furnish sufficient supplies for camp and for wandering bands of sheep. Eleven valleys on the slopes of Carrizo Mountain hold in their upper courses tiny rills of perennial flow. Only three of these—Walker Creek, Biltabito, and Tisnasbas—flow continuously from the top to the base of the mountain during the dry season, and the discharge from the largest of these streams, Tisnasbas, was found by Dr. Emery, in July, 1913, to be 0.20 second-foot. On Black Mesa one permanent stream was observed, in addition to several short trickling rills, the outflow from springs. This stream, the Tahchito, maintains a flow of 20 to 30 gallons a minute for a distance of about 5 miles.

DRAINAGE OBSTRUCTED BY DUNES.

Valleys trending southwest from Shato Plateau furnish a resting place for the wind-blown sand stripped from the surface of Kaibito Plateau, and the streams in the valleys are accordingly blocked from place to place. After rains Shato and Begashibito brooks are merely a series of lakes and pools tied together by streams. During the dry season the valley axis resembles a string of beads and the flow of the stream is so completely interrupted that lakes bordered by vegetation are separated from one another by stretches of dry floor heaped with dunes.

EPHEMERAL STREAMS.[1]

The through-flowing and intermittent streams described above traverse less than 1 per cent of the linear extent of drainage channels in the Navajo country. During the dry season the ratio of valleys occupied by streams to valleys without water is, for channels exceeding 25 miles in length, about 1:100, and for channels between 5 and 10 miles in length about 1:340. Except during the rainy season the area drained by perennial surface waters is perhaps less than 5 per cent of the 25,725 square miles constituting the area under

[1] On the map (Pl. I) ephemeral streams are not separately indicated. The longer ones are included with "intermittent" streams; most of them are not shown.

discussion. No permanent stream, except the Moenkopi, was found west of the Chinle Valley and south of latitude 36° 14′, a district constituting about one-half of the reservation. The Kaibito Plateau and a large part of the Gothic Mesas are also without perennial drainage.

With the coming of the rains conditions are radically modified and the dry valley floors are covered with rivers and tributary brooks. A single shower may convert any one of a score of intermittent rills into a through-flowing stream, and raise a group of dry washes to the dignity of rivers. During the season of daily rains, the last part of July and August, the aspect of the country is entirely changed. The Chinle system becomes integrated, and tributaries of the third and fourth degree contribute their daily supply. During this period the forbidding dry, hot valleys leading to the Little Colorado are transformed into a series of silt-laden rivers exceeding 100 miles in length, and the Little Colorado itself becomes a river of commanding proportions, ranking with the Gila and the San Juan in the volume of water carried to the Colorado. Throughout the extent of the Navajo country the ephemeral or seasonal stream is the prevailing type, and all studies relating to the development of water resources in the Colorado Plateau province should include this factor of primary importance.

SUMMARY TABLE OF STREAMS.

The drainage area, length, and type of stream on the reservation are indicated in the following table. Distances and areas and the relation of tributaries to master streams are based on the reconnaissance topographic maps of the United States Geological Survey; statements regarding the characteristics of the streams are taken from field notes, supplemented by information supplied by Navajos, Indian traders, and Government officers.

Principal streams of the Navajo country.

Name.	Drainage area.	Length.	Type.	Character of water.
	Sq. miles.	*Miles.*		
Puerco and Little Colorado.	9,897	252		Heavily silt laden except at low water.
Puerco River	1,326	97	Intermittent	
Black Creek	272	61	Perennial 16 miles at head; perennial for 6 miles below Oak Spring; remainder intermittent.	Clear, fresh.
Bonito Creek	38.5	4	Perennial	
Lithodendron Creek	156	28	Ephemeral	
Little Colorado below junction with Puerco.	8,571.5	156	Perennial between Holbrook and Winslow; intermittent for 5 miles below Winslow; ephemeral 92 miles.	Muddy except at extremely low water; slightly alkaline and salty.
Leroux Wash	203.5	23	Ephemeral	
Pueblo Colorado Wash.	1,247	56	Intermittent 10 miles at upper end; perennial for 8 miles above Ganado; ephemeral from Ganado to mouth.	

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Principal streams of the Navajo country—Continued.

Name.	Drainage area.	Length.	Type.	Character of water.
	Sq. miles.	*Miles.*		
Wide Ruin Wash	445	38	Ephemeral	
Cottonwood Wash	527.5	58	do	
Corn Creek (from Tolani Lakes to mouth).	49	13	do	
Coyote Wash	338.5	28	do	
Jadito Wash	623	50	do	
First Mesa Wash	672.5	56	do	
Wepo Wash	179	21	do	
Second Mesa Wash	67	30	do	
Oraibi Wash	652	85	do	
Dinnebito Wash	872	100	do	
Moenkopi Creek, not including Red Lake Valley drainage.	969	76	Perennial 35 miles; intermittent 18 miles; ephemeral 23 miles.	
Moenkopi Wash (Tuba to mouth).	367	20	Perennial except for short stretches	Alkaline.
Red Lake and Klethla valleys.	312	46	Ephemeral except at lower end	
Colorado River drainage	1,877	162	Perennial	Heavily silt laden.
Navajo Creek	770	54	do	Clear, fresh, except in flood seasons.
Bridge Creek	23	7	do	Clear, fresh.
San Juan River drainage (San Juan River below Farmington).	13,951	220	do	Silt laden except at low water.
Piute Creek	285	35	do	Fresh, clear, except in flood seasons.
Nokai Creek[a]	246	34	do	Do.
Copper Creek[a]	26	14	do	Fresh, clear.
Moonlight Creek (including Segihatsosi drainage).	477	42	Perennial 4 miles; intermittent 18 miles; ephemeral 20 miles.	Clear, fresh, in upper portions.
Gypsum Creek	169	30	Perennial, lower portion	Alkaline; unpalatable.
Chinle Creek (or wash).	4,790	104	Ephemeral 86 miles; intermittent 18 miles.	Silt laden except at lowest stages.
Walker Creek	387	38	Perennial	Clear, fresh.
Tyende Creek	975	62	do	Do.
Lukachukai Creek	325	30	Perennial 10 miles; intermittent 14 miles.	Clear, fresh from source to Round Rock; slightly alkaline below.
Agua Sal Creek	103.5	24	Ephemeral 6 miles; intermittent 8 miles; ephemeral 16 miles.	Reported to be alkaline.
Canyon de Chelly Creek	162.5	20	Perennial 15 miles; intermittent lower 5 miles.	Fresh, clear, except in flood.
Spruce Brook	73	18	Perennial	Clear, fresh.
Canyon del Muerto Creek	107.5	17	Intermittent	Do.
Wheatfields Creek	87	16	Perennial	Do.
Palisade Creek	16	8	do	Do.
Whiskey Creek	49	9	do	Do.
Simpson Creek	80.5	12	Perennial 10 miles; ephemeral 2 miles.	Fresh, clear, except lower 4 miles.
Monument Creek	100	16	Intermittent	Fresh, clear.
Nazlini Creek	243	24	Perennial 9 miles; intermittent 3 miles; ephemeral 12 miles.	Fresh, clear, in canyoned portion.
Beautiful Valley Wash	155	28	Ephemeral	
Gothic Wash	197	25	do	
Desert Creek	87	15	do	
Arido Creek	166	25	Ephemeral or intermittent	
Tisnasbas Creek	73.5	18	Perennial 6 miles; intermittent 2 miles; ephemeral 10 miles.	Fresh, clear, in upper portion.
Biltabito Creek	64	15	Perennial 3 miles; intermittent 4 miles; ephemeral 8 miles.	Fresh, clear, in perennial portion.
Red Wash	521	30	Intermittent; ephemeral	Slightly alkaline except at head tributaries.
Standing Redrock Creek.	67	13	Perennial 9 miles; intermittent 2 miles; ephemeral 2 miles.	Clear, fresh.
Blackhorse Creek	46	12	Perennial 3 miles; intermittent 9 miles.	Do.
Rio Chaco	4,791	82	Ephemeral with intermittent stretches.	

[a] The area drained and the length of Nokai Creek are rough approximations only. The topography of this area as shown on the Marsh Pass and Henry Mountains maps gives an erroneous idea of the drainage relations of Copper, Nokai, and Piute canyons.

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FACTORS INFLUENCING STREAM FLOW.

PRECIPITATION.

AMOUNT.

With the exception of the San Juan, the Colorado, and the Little Colorado, the streams of the Navajo country are fed by water that falls within its borders. The annual mean precipitation has been determined at a few points (see pp. 50–59) and found to be small in amount and to vary widely at different localities. The records for Fort Defiance and St. Michaels, at elevations of about 6,900 feet, giving a mean annual fall of 12.80 inches, represent fairly the combined rainfall and snowfall for Defiance Plateau, Black Creek Valley, Manuelito Plateau, and Dutton Plateau, are doubtless somewhat too low for the Chuska Mountains and Carrizo Mountain and are probably slightly too high for Black Mesa.

The mean annual precipitation of 10.62 inches at Chinle (elevation about 6,400 feet) is probably higher than for Chinle Valley as a whole, as well as for Monument Valley and the Gothic Mesas. The average annual precipitation at Holbrook is 9.15 inches. It may be noted that evaporation at Holbrook during this same period averaged 46.32 inches, that is, more than five times the amount of rainfall. These figures may reasonably be extended to cover the Hopi Buttes, the Tusayan Washes, and the upper Puerco and Little Colorado Valley.

The area centering at Tuba is the most arid part of the Navajo country. The records of rainfall at this station give an average precipitation of 5.30 inches, a figure that may be extended to cover the Kaibito Plateau, and possibly also the Moenkopi Plateau and a large part of the Rainbow Plateau. Judging from the vegetation, Shato Plateau and Segi Mesas receive 20 to 30 per cent more rain than is recorded at Tuba. On the other hand the precipitation in the Painted Desert below Grand Falls probably reaches, on the average, less than 3 inches, and in some years the total rainfall has been insufficient to produce run-off. On one occasion, according to reports of a Navajo headman, two years in succession were marked by the absence of rain at Tanner Crossing.

Navajo Mountain, which rises 4,000 feet above its plateau base, is visited by rainclouds which pass unchanged across the lower lands to the west and probably receives precipitation, including snow, of more than 20 inches, sufficient to support a relatively luxuriant vegetable cover. A mean annual precipitation of 6.92 inches at Hite, Utah, 40 miles north of the mouth of San Juan River, may be taken as representative of the immediate valley of Colorado River from Lee Ferry to the mouth of Fremont River. The rainfall along the middle and upper San Juan Valley is fairly repre-

pressure is released by puncturing the roof of the reservoir, as by a well drill, the water rises through the impervious stratum which hitherto has confined it. The pressure may be sufficient to force to the surface the water from this deep-seated reservoir or may be only enough to cause a rise of a few feet. In either event the water is "artesian," for this term is applied to all ground waters that show an appreciable rise when struck, whether or not the pressure is sufficient to produce flows at the surface. In the Navajo country artesian water has been found on the Chaco Plateau and is believed to be present in Chuska Valley, the upper Chinle Valley, in the northern part of Gothic Mesas, and to a less extent elsewhere. Such areas are reserved for description in connection with a discussion of wells (pp. 176–183).

SPRINGS.

DISTRIBUTION AND CHARACTER.

One of the surprises that awaits the traveler in the Navajo country is the large number of springs widely distributed over the reservation. Tucked away in alcoves in the high mesa walls or issuing from crevices in the canyon sides or bubbling up through sands in the long wash floors, these tiny supplies of water appear to be distributed in haphazard fashion. Few of the hundreds of little springs yield more than a gallon a minute; some of them are charged with salts, and many of them are accessible only to a man on foot. Safe traveling in this region involves a knowledge of the location of these springs, and exploration consists essentially in directing one's course from spring to spring. The ancient cliff dweller was well aware of the desirability of these small permanent supplies as centers for settlement, and many of the present-day Indian trails owe their position to the location of springs rather than to topography or to length of route.

The chief reason why the springs of the reservation are so clearly defined is the boldness of the topography. Valley floor meets canyon wall or mesa face or mountain border abruptly. High walls of bare rock in many places join the alluvial fill of washes at angles approaching 90°. There is a singular absence of talus and of fans flanking the highlands. Springs therefore emerge directly from rock walls without the intervention of a cloak of sands, gravels, and bowlders, which tend to conceal the opening by which ground water leaves the rock. Also the recent cutting of the floors in alluvium-filled canyons has exposed the point of emergence of water formerly hidden from view. An additional reason for the individuality of springs is their more or less complete separation from the perennial drainage and their independence of the short-period fluctuations in rainfall and

ephemeral stream flow. In general the springs flow from a definite spot rather than from an undefined area of swamp, and their waters rarely extend far from the exit.

Nearly all the springs on the reservation are of the normal type—that is, they mark points of escape of ground water which has entered the rock or alluvium at higher levels and found its way downward and outward through cracks, between grains, and along bedding planes. A few springs are artesian in character and reach the surface only after finding an opening in impervious beds through which the water is forced upward by pressure exerted at some distant locality. The Boiling Spring (Navajo, Tohalushi) in Laguna Canyon and the Mud Springs at Tuye on the Chaco Plateau illustrate flows which escape under pressure from retaining beds of clay and silt.

With respect to mode of origin the springs of the Navajo country may be grouped in five classes, namely, springs in unconsolidated materials, springs between ledge and alluvial cover, springs emerging from the contact of two rock strata, springs within a single stratum, and springs emerging from fault lines.

SPRINGS IN UNCONSOLIDATED DEPOSITS.

GENERAL RELATIONS.

Springs issuing from unconsolidated deposits are found in the bottoms of the main washes and their tributaries, on slopes buried with talus, or within materials of alluvial fans. An alternation of porous and relatively impervious layers is essential, otherwise the percolating water tends to sink downward to join the permanent ground-water reservoir from which it may be recovered only by means of wells. The most favorable arrangement is a series of beds of clay and adobe interstratified with sands or gravels—a series of strata whose edges are exposed by erosion. Springs of this type emerge on flat or sloping surfaces, or directly from alluvial walls bounding arroyos, and their presence is indicated by bogs or by areas of sand through which water bubbles continuously or intermittently in response to precipitation and evaporation. In many places the water feeding the spring is held near the surface; elsewhere the water-bearing bed lies some distance below the surface and the outlet slopes obliquely upward, traversing porous lenses in the alluvium.

At St. Michaels two short canyons with numerous tributaries unite to form a wash whose floor is so thoroughly saturated with water that native grass has a luxuriant growth. This is the well-known meadow Cienega Amarilla. From the walls of arroyos in the meadow springs issue at a definite horizon between coarse and fine sands. (See Pl. XXVI, *B*, p. 111.) The supply from these springs

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