

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Ground Water Branch

GROUND-WATER RESOURCES OF THE BRYCE
CANYON NATIONAL PARK AREA, UTAH

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Open-File Report

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PARK AREA, UTAH

By I. Wendell Marine

A B S T R A C T

The water need at Bryce Canyon National Park in 1957 was about 1.3 million cubic feet for a tourist season that lasted from the middle of May to the middle of October. In order to evaluate the adequacy of water-supply sources, a hypothetical future need of 5 million cubic feet of water per season is used. This amount of water might be obtained from the East Fork of the Sevier River, from wells in the alluvium of the East Fork, from Yellow Creek Spring and nearby springs, which are below the rim, or from a well drilled approximately 2,000 feet to the top of the Tropic shale. The present source of water, consisting of wells in the alluvium of East Creek valley, could be an important source in the future, but the existing well field will not yield sufficient water in dry years to be the sole source of water for the Park.

It is estimated that Yellow Creek Spring and nearby springs could yield a total of 7.8 million cubic feet of water per season. The water from these springs is of satisfactory chemical quality, and this source is reliable even in times of drought. A serious disadvantage of using this source of water is that a pipeline

would have to be constructed over difficult terrain to connect it with the lodge and headquarters area.

A well drilled to the top of the Tropic shale in the lodge and headquarters area might penetrate two or more aquifers, one at the base of the Wasatch formation and one or more in the Wahweap and Straight Cliffs sandstones. The yield of this well would depend to a large degree on the number of fractures encountered. In order to assure the most favorable conditions for intercepting fracture zones in the bedrock, a test-well site is proposed near the crest of a gentle anticline where tension fractures in the rocks should be common.

Shallow wells in the alluvium of East Creek valley cannot be depended upon to yield sufficient water in times of drought, but they are nevertheless an important source. The water-storage capacity of the alluvium of East Creek valley in the vicinity of the Utah Parks Co. wells is estimated at 1.4 million cubic feet. If the water table in the valley could be lowered uniformly without creating excessively large cones of depression, the alluvium could supply the 1.3 million cubic feet of water per season estimated as the water need in 1957. However, in times of drought this alluvium could not supply the 5 million cubic feet of water per season specified as the hypothetical future need.

INTRODUCTION

Purpose and Scope

The purpose of this investigation was to appraise the ground-water resources of Bryce Canyon National Park area and vicinity. This appraisal is intended to furnish sufficient information for the National Park Service to decide how and where to develop an adequate water supply.

The National Park Service's water system, which is the only one available for year-round use in Bryce Canyon National Park, consists of one well (headquarters well) that yields about 160 gpd (gallons per day), enough to supply the needs of one family; one 5,000-gallon storage tank; and pipelines for the distribution of water. The Park Superintendent estimates that about 1,000 gpd was needed to supply the seven Park Service families that domiciled in the Park during the winter of 1956-57. During the summer the Park Service's water system is connected into the water system of the concessioner (the Utah Parks Co.), and the shortage of water for the Park Service families is alleviated. The water-supply system of the concessioner, however, is inadequate to supply all the water needs of the Park for an entire season in times of drought. Because the "MISSION 66" program includes plans for the expansion of the overall facilities at Bryce Canyon National Park, a water supply much larger than that now provided by the concessioner is needed.

Figure 1 shows the general increase in the number of visitors to Bryce Canyon National Park in past years and the estimated future range of attendance under the "MISSION 66" program. Any water supply that is planned should be able to meet not only the present water needs of the Park but also the needs of the future.

The principal objectives of this investigation were to determine the quantity, quality, and dependability of all possible sources of water supply for the Park. Because the water supply is needed in the lodge and headquarters vicinity, special emphasis was placed on sources that are within several miles of that area.

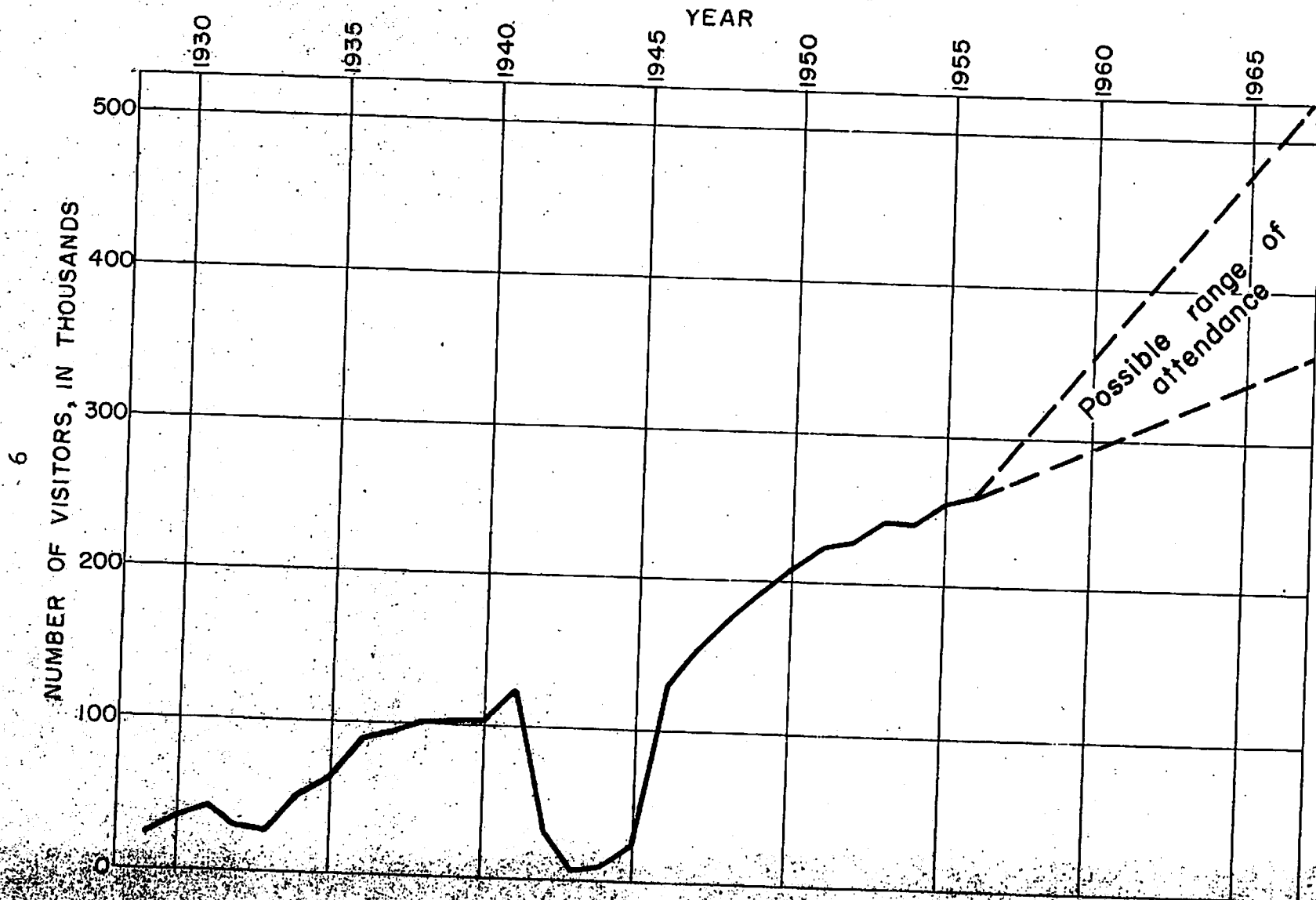


Figure 1.-- Number of visitors to Bryce Canyon National Park, 1930-1965, and range of possible future attendance. Data through 1965 are based on actual attendance.

Location of the Area

The area of this report is in and adjacent to Bryce Canyon National Park (see inset, fig. 2). The Park is in Kane and Garfield Counties, south-central Utah, between $37^{\circ}42'$ and $37^{\circ}26'$ north latitude and $112^{\circ}05'$ and $112^{\circ}17'$ west longitude. It is also on the divide between the Paria River, a tributary to the Colorado River, and the East Fork of the Sevier River, which drains into the Great Basin.

Previous Investigations

The geology of the Paunsaugunt Plateau region was described by Herbert E. Gregory in a report (1951) that includes brief discussions of the ground-water resources of the region and of some of the most important wells and springs, and a geologic map which was used extensively in carrying on the present investigation. Williams (1954) gave a synopsis of the stratigraphy and structure of the Paunsaugunt Plateau region. A report by Gregory and Moore (1931) referred in part to the geology of the area. The U. S. Geological Survey published in 1939 a topographic map of Bryce Canyon National Park and adjacent area which was extremely useful in the present investigation.

A 3-day reconnaissance of the Campbell Canyon Spring and Bryce Canyon Spring areas was made in April 1954 by Ben E. Lofgren, engineer, U. S. Geological Survey. This reconnaissance included no discharge measurements, but on the basis of it Mr. Lofgren suggested to Park Service personnel that the Campbell Canyon Spring might be used for a Park water supply.

Personnel and Acknowledgments

This investigation was made under the direct supervision of Herbert A. Waite, district geologist of the U. S. Geological Survey in charge of ground-water investigations in Utah. Glen T. Bean, Superintendent of Bryce Canyon National Park, and all the employees of the National Park Service at Bryce Canyon rendered valuable assistance in all phases of the investigation. Donald Price, geologist, Ground Water Branch, assisted the writer for 2 weeks in the field investigations. Robert Burns, former Supervisory Park Ranger, and Robert Ott of the National Park Service were very helpful in guiding the writer to significant springs in the area.

GEOGRAPHY

Bryce Canyon National Park lies at the east edge of the Paunsaugunt Plateau, one of the high plateaus of southern Utah, and includes part of the plateau, the rim, and the foothills bordering the plateau at a lower elevation. The altitude of the plateau top in the Park ranges from about 7,600 to more than 9,000 feet. The climate of this part of the Park is generally cold except in the summer months. Below the rim the foothills have relief that is as great as 1,000 feet. The temperature below the rim is generally higher than on the plateau, and the summers are longer. Figure 3 shows the annual precipitation and departure from normal at Bryce Canyon National Park from 1933 through September 1957. It also shows cumulative departure from normal precipitation. The weather station is at the headquarters, on the plateau.

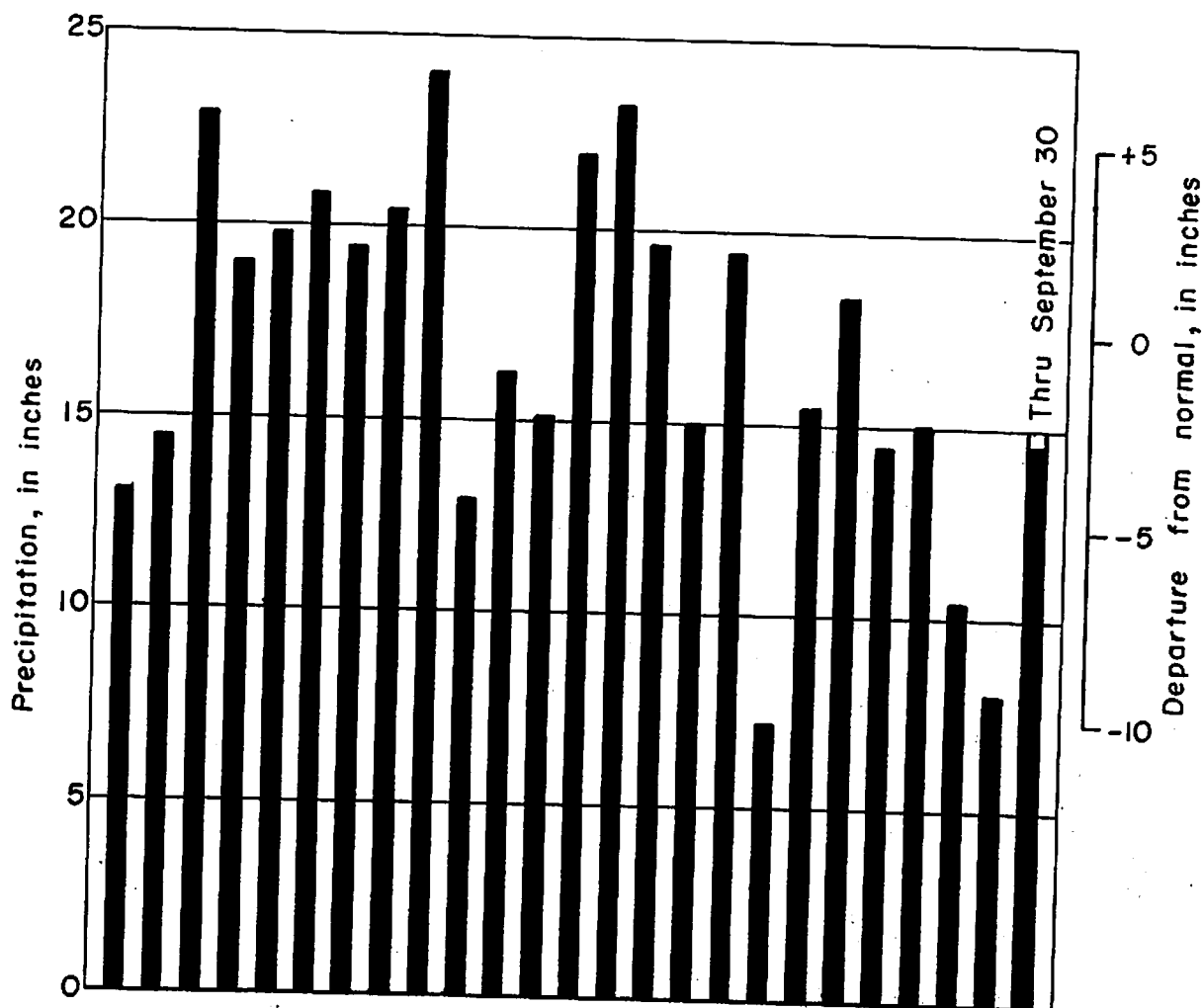
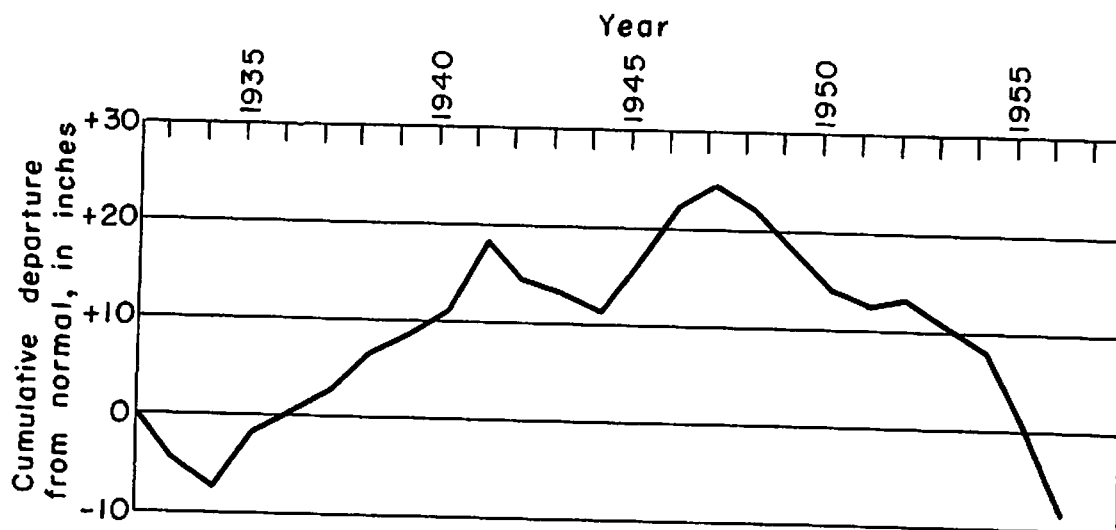


Figure 3. -- Annual precipitation and cumulative departure from normal at Bryce Canyon National Park, Utah.

Water Use

The principal water users in Bryce Canyon National Park and vicinity are the public and employees using the Park Service and concessioner water systems, the town of Tropic, and the Tropic and East Fork Irrigation Co. Other water users in the area obtain small supplies from wells or springs. The town of Tropic is supplied from Bryce Spring through a pipeline about $2\frac{1}{2}$ miles long (fig. 2). The Tropic and East Fork Irrigation Co. obtains water from the East Fork of the Sevier River and transmits it via the Tropic Ditch across part of the plateau, down Water Canyon, and into the vicinity of the town of Tropic where it is used for irrigation. The diversions of the Tropic and East Fork Irrigation Co. for the last 7 years (1950-56) are listed in table 1. Water is used in Bryce Canyon National Park for general purposes at the lodge, cafeteria, and campground and for domestic purposes by the Park Service personnel and the employees of the Utah Parks Co.

For many years some water has been supplied to the Park facilities from Trough and Shaker Springs, but in 1956 and 1957 these springs were dry. For the past several decades some water has been obtained from springs in East Creek valley. In July 1955 the springs in that valley had so decreased in yield that it became evident they would not supply water through the rest of the season, and in that month well 1 was drilled (figs. 4 and 5). This well was the sole source of water supply for the Park from July 1955

Table 1.-- Tropic Ditch diversions of the Tropic and
East Fork Irrigation Co. U. S. Geological
Survey gaging station 5 miles below Daves
Hollow.

Month	Flow in ditch in acre-feet						
	1950	1951	1952	1953	1954	1955	1956
April	138	-	-	-	-	-	-
May	1,130	691	976	287	726	518	296
June	1,110	837	1,060	549	720	392	360
July	612	427	1,170	455	490	347	.2
Aug.	650	289	999	178	104	256	3.8
Sept.	263	84	738	107	136	437	212
Oct.	-	68	42	301	1	104	62
Total	3,900	2,400	4,980	1,880	2,180	2,050	934



Figure 4.-- Water-supply developments of the Utah Parks Co. in East Creek valley showing wells 1, 2, and 3; a developed spring (4); the spring-collector sump (5); and the spring pumphouse (6). Note flat-floored valley bordered by bedrock side slopes.

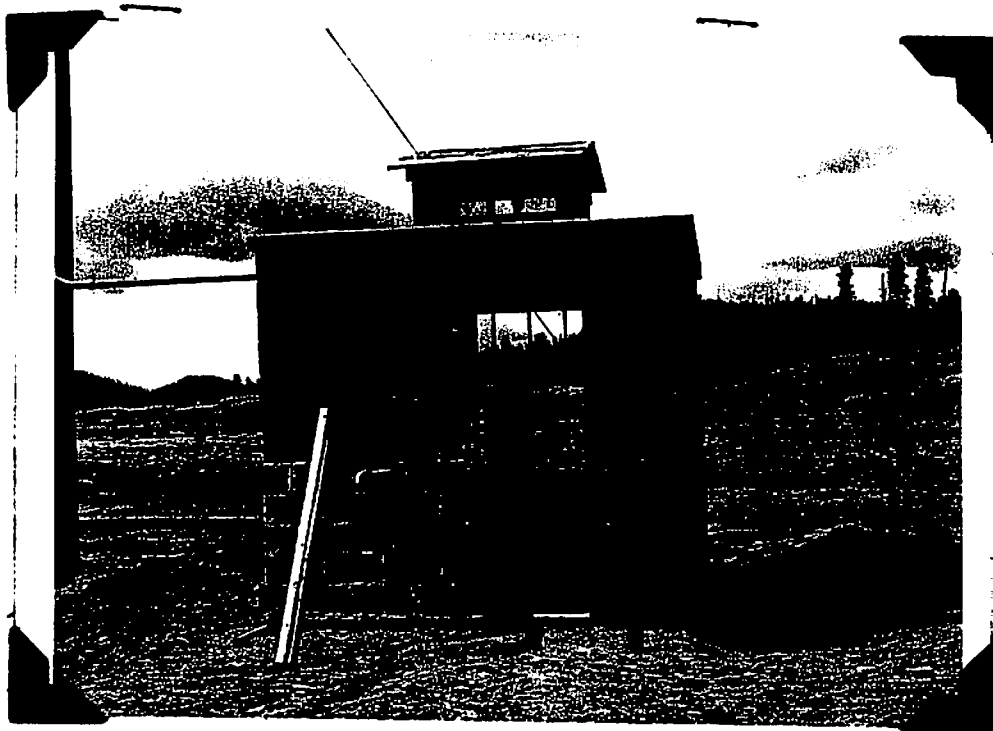


Figure 5.-- Utah Parks Co. well 1 and pumphouse. This well was the sole source of water for Bryce Canyon National Park from July 1955 to August 1957.

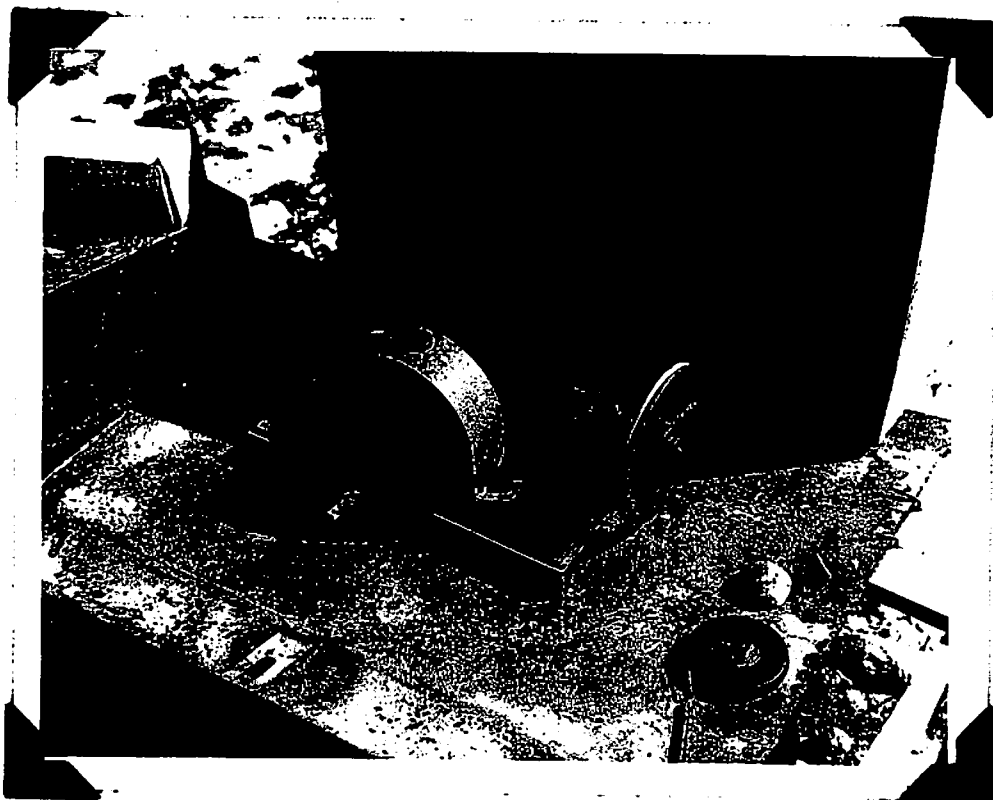


Figure 6.-- Water-level recording gage on Utah Parks Co. well 3.

to August 1957. It is reported that the springs dried up completely after the well pump was installed and that they did not flow in 1956. In May 1957 there was a small overflow from the spring collector sump (fig. 4), but by June of that year there was none. In February 1957 two additional wells were drilled in East Creek valley. Upon completion the wells were tested by Utah Parks Co. personnel to determine their yield. No measurements of water level were made during these tests. The results of each test are summarized as follows:

Well	Yield (gpm)	Time (hours)	Pump setting below land surface (feet)
1	180	8	18
2	90	8	24
3	25	Tested for short period and pump broke suction.	

The average of four separate measurements of the discharge of well 1 made at the Utah Parks Co. storage tanks in May 1957 was 55 gpm. Three check measurements were made in July 1957, and still the average was 55 gpm. It should be emphasized that this was the water delivered at the tanks and available for use; it was not necessarily the same as the amount of water discharged by the well, as there may have been leaks in the 4 miles of pipeline between the pump and the tanks. In the parts of the pipeline seen by the writer, however, there were no leaks, and it is assumed in the rest of this report that 55 gpm was the discharge rate of well 1.

Water-level recording gages were installed on wells 2 and 3 (see fig. 6). The records from these wells show within 15 minutes when the pump on well 1 begins to operate. These recording gages therefore are valuable not only to record water-level fluctuations in the basin (fig. 7) but also to indicate the duration of pumping. Table 2 shows the total number of hours that the pump was in operation during each month from April through November 1957.

On August 2, 1957, well 1 began to pump air, and from that date to the end of the season the amount of water pumped was not a true indication of the need for water in the Park. The amount of water pumped in the first half of the tourist season may be used as a basis for estimating the need for water in the Park. During the season, July and August are the months of maximum pumping and May and October the months of least pumping. The pump is started about May 1 and stopped about November 1. Assuming that the pumpage in August is about the same as in July, September the same as June, and October the same as May, it is estimated that the water need for one entire season (as of 1957) is approximately 1.3 million cubic feet. Owing to the rapid drop in demand after Labor Day, this figure may be slightly high, but it cannot be far off because the actual pumpage in 1957 was in excess of 1.1 million cubic feet, and more would have been pumped if well 1 had held up. On the basis of the "MISSION 66" design of facilities for 500,000 visitors, a water need of about 5 million cubic feet per season is selected as a basis for the comparison of various sources of water. A summary of these figures is given in table 3.

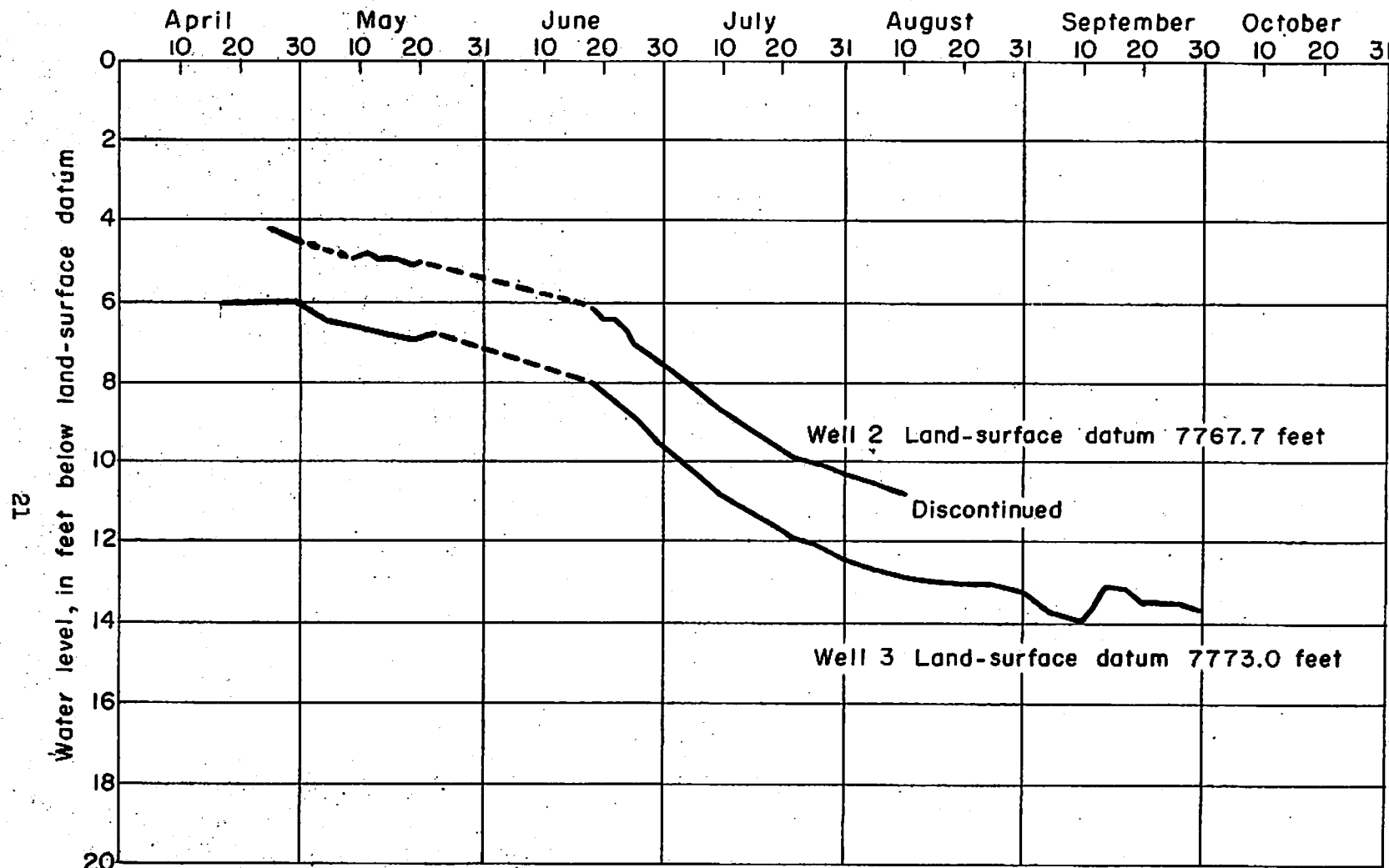


Figure 7.-- Hydrographs of two observation wells in the alluvium of East Creek valley, April to September 1957. Well 2 is 451 feet from the pumping well; well 3 is 245 feet from the pumping well.

Table 2.-- Monthly pumpage from Utah Parks Co. well field in East Creek valley during 1957 and the net decline in water level each month in well 3.

Month	Total time of pumping (hours)	Water pumped			Net decline in water level in well 3 (feet)
		Gallons	Cubic feet	Acre-feet	
Apr.	0	0	0	0	0
May	299	986,700	131,500	3.04	1.1
June	478	1,577,400	213,000	4.89	2.5
July	714	2,356,200	314,000	7.22	3.0
Aug.	^{a/} 496	1,636,800	219,100	5.04	.8
Sept.	^{a/} 338	1,115,400	148,700	3.41	.4
Oct.	^{a/} 200	660,000	88,000	2.02	.2
Nov.	0	0	0	0	0
Total	2,525	8,332,500	1,114,300	2,562	8.0

^{a/} Well started pumping air on August 2. These figures do not represent the amount of water that would have been pumped if the supply had been adequate.

Table 3.-- Summary of quantities of water available from selected sources compared to present water use and hypothetical water needs in Bryce Canyon National Park, Utah.

	Maximum quantity measured in 1957 (gpm)	Total quantity per 4½-month season		Estimated yield after development work (gpm)	Total quantity per 4½-month season (based on estimated yield)	
		Millions of gallons	Millions of cubic feet		Millions of gallons	Millions of cubic feet
Present water use	55	a/9.7	a/1.3	-	-	-
Hypothetical water need for planning purposes	-	39	5	-	-	-
Water available from alluvium of East Creek	b/55	c/8.3	c/1.1	55	d/10	d/1.4
Water available from Campbell Canyon Spring	28	5.4	.7	50	9.7	1.3
Water available from Merrill Ranch Spring	24	4.7	.6	35	6.8	.9
Water available from Yellow Creek Spring	81	16	2.1	110	21	2.9
Water available from Yellow Creek Spring and Yellow Creek Wash Spring	201	39	5.2	300	58	7.8
Water available from Right Fork of Yellow Creek	75	15	1.9	75+	14.6+	1.9+
Estimated yield from bedrock well (based on meager information)	-	-	-	e/ 30-300	5.8-58	0.8-7.8

a/ Represents the estimated amount of water that would have been pumped if well 1 had not started to pump air.

b/ Well field would not sustain this yield. Well 1 began to pump air August 2, 1957.

c/ Actual withdrawal from alluvium of East Creek.

d/ Based on a sustained yield of 55 gpm.

e/ Depends on the number of fractures encountered.

GEOLOGY

Stratigraphy

Paleozoic rocks

The oldest rock formation known to underlie the Bryce Canyon area is the Redwall limestone of Mississippian age. This formation was penetrated at a depth of 10,189 feet below the surface in an oil test in Johns Valley (table 4) about 12 miles northeast of the lodge and headquarters area (off fig. 2). This same test hole passed through 759 feet of Pennsylvanian strata belonging to the Molas and Hermosa formations. Rocks of Permian age were penetrated in the Lion Oil Co. test hole 4 miles northwest of the lodge and headquarters area (fig. 2 and table 4). These rocks were the Coconino sandstone, the Toroweap formation, and the Kaibab limestone.

Table 4.-- Logs of wells and auger holes in the Bryce Canyon National Park area, Utah. (See figs. 2 and 9 A for location.)
(All water levels in this table are in feet below land surface.)

	Thickness (feet)	Depth (feet)
Headquarters well, National Park Service.		
Yield - 160 gallons per day; diameter - 48 in. to 30 ft, 12 in. to 50 ft., 8 in. to 80 ft.		
Static water level - 49 ft.		
Alluvium		
Old dug well		
Wasatch formation	30	30
Rock	10	40
Fractured rock	10	50
Rock	30	80
Well 1, Utah Parks Co.		
Yield - 180 gpm; diameter - 12 in.		
Alluvium		
Clay	12	12
Gravel	3	15
Porous formation	9	24
Tight formation	6	30
Wasatch formation		
Dry chalky formation	50	80
Well 2, Utah Parks Co.		
Yield - 90 gpm; diameter 12 in.		
Static water level - 4 ft.		
Alluvium		
Clay	6	6
Sand and gravel	4	10
Clay	2	12
Gravel	2	14
Clay	4	18
Gravel and sand	8	26
Clay	4	30
Wasatch formation		
Rock	-	30+

Daves Hollow Ranger Station, Forest Service.
 Yield - 90 gallons per hour; diameter - 6 in.
 Static water level - 15 ft.

	Thickness (feet)	Depth (feet)
Alluvium		
Clay, sandy, and gravel	20	20
Kaiparowits formation		
Clay, sandy, gray	15	35
Clay, sandy, gray (water)	15	50
Clay, sandy, gray	60	110
Clay, sandy, gray (very hard)	12	122
Shale, sandy, brown (caving)	3	125
Clay, sandy, gray	82	207

Bryce Canyon Airport, Civil Aeronautic Authority.
 Yield - 10 gpm; diameter - 6 in.
 Static water level - 33 ft.

Alluvium		
Conglomerate and hardpan	12	12
Clay, yellow	4	16
Clay, light brown	7	23
Clay, blue-gray	11	34
Clay, gray-brown	9	43
Clay, sandy, light-brown	5	48
Clay, sandy, light	3	51
Kaiparowits formation		
Sandstone, gray	40	91
Shale, gray	8	99
Shale, sandy, blue	26	125
Shale, sandy, hard, blue	2	127
Shale, sandy, blue	9	136
Shale, sandy, hard, blue	2	138
Shale, sandy, soft	12	150

Sawmill Well, E. A. Crofts.
 Yield - 40 gpm; diameter - 6 in.
 Static water level - 18 ft.

Alluvium		
Clay	20	20
Sand (little water)	15	35
Clay	25	60
Gravel (water)	6	66
Kaiparowits formation		
Shale, light-gray (no water)	244	310

Lion Oil Co. water well.
Yield - 10 gpm; diameter - 6 in.

	Thickness (feet)	Depth (feet)
Alluvium		
Sand rock	70	70
Rock formation, porous	6	76
Sand rock	40	116
Rock formation, porous	6	122
Sand rock	8	130
Rock, porous	6	136

Lion Oil Co. oil test

Kaiparowits formation, Wahweap and Straight Cliffs sandstones	940	940
Tropic shale	1,305	2,245
Dakota sandstone	415	2,660
Morrison formation	1,965	4,625
Carmel formation	1,430	6,005
Navajo sandstone	2,075	8,130
Chinle formation, upper part	598	8,728
Shinarump member of Chinle formation	129	8,857
Moenkopi formation	1,125	9,982
Timpoweap member of Moenkopi formation	104	10,086
Kaibab limestone	479	10,565
Toroweap formation	451	11,016
Coconino sandstone	205	11,221

The Pines Motel, Mayo Rich

Diameter - 6 in.

Static water level - 15 ft.

Alluvium		
Clay, sandy	10	10
Wasatch formation		
Sand rock, red	160	170

Forest Oil Corp. oil test (about 3 miles west
of Lion Oil Co. oil test, off fig. 2)

Wasatch formation	496	496
Kaiparowits formation	155	651
Wahweap sandstone	231	882
Straight Cliffs sandstone	2,398	3,280
Tropic shale	1,130	4,410
Dakota sandstone	218	4,628
Winsor formation	507	5,135
Entrada sandstone	470	5,605
Carmel formation	586	6,191
Navajo sandstone	51	6,242

California Co. oil test, Johns Valley
no. 1 in sec. 22, T. 35 S., R. 2W.

	Thickness (feet)	Depth (feet)
Wahweap and Stright Cliffs sandstones	910	910
Tropic shale	898	1,808
Dakota sandstone	202	2,010
Morrison formation	685	2,695
San Rafael group	955	3,650
Glen Canyon group	2,085	5,735
Chinle formation, upper part	560	6,295
Shinarump member of Chinle formation	75	6,370
Moenkopi formation	995	7,365
Kaibab limestone	923	8,288
Coconino sandstone	1,022	9,410
Hermosa formation	713	10,123
Molas formation	66	10,189
Redwall limestone	146	10,335

Logs of auger holes in alluvium of East Creek valley	Thickness (feet)	Depth (feet)
Auger hole 1		
Sand, clayey, tan	14	14
Gravel and sand, tan (water)	-	14½
Auger hole 2		
Sand, clayey, tan	2½	2½
Gravel and sand, tan (dry)	-	2½
Auger hole 3		
Soil, dark clayey	2	2
Gravel and clay, light-brown	2	4
Gravel, angular, white (water)	1	5
Auger hole 4		
Clay, sticky, gray-brown	2	2
Sand, clayey, brown	2	4
Gravel, fine; sand and clay, tan	2	6
Gravel, coarse, reddish-white (water)	1	7
Auger hole 5		
Soil, sandy, dark-gray	2	2
Clay, sticky, gray	2	4
Clay, sticky, yellow	4	8
Gravel, sand and clay, yellow (water)	-	8
Auger hole 6		
Soil, clayey, black	2	2
Clay, sticky, black	2	4
Clay, sandy, (water)	1	5
Auger hole 7		
In gully about 15 feet below general land surface.		
Bank of gully - red sand	15	15
Red sand	6½	21½
Gravel (dry)	-	21½
Auger hole 8		
Clay, sandy, dark-gray	8½	8½
Gravel and clay, white	1½	9
Sand, reddish-white	1½	10½
Gravel (dry)	-	10½
Auger hole 9, Daves Hollow		
Pit	4	4
Clay, sticky, red	8	12
Sand, fine, red	1	13
Gravel, reddish-white (dry)	1	14

Mesozoic rocks

Table 5 shows the thickness and geologic character of the Mesozoic and Cenozoic rocks underlying Bryce Canyon National Park. The shales and sandstones of the Moenkopi formation, about 500 feet thick in the Bryce Canyon area, are Early and Middle (?) Triassic in age. Above these beds is the Shinarump member of the Chinle formation, a red and gray conglomerate here about 100 feet thick. The rest of the Chinle formation, consisting of about 600 feet of red and brown shale and limestone, makes up the upper part of the Triassic system.

The Jurassic system is made up of three principal parts: the Glen Canyon group, the San Rafael group, and the Winsor formation. The Glen Canyon group in the Bryce Canyon area consists of only one formation, the Navajo sandstone. It is an intensely crossbedded white consolidated dune sand about 1,200 to 1,800 feet thick. The San Rafael group consists of three formations: the Carmel formation, Entrada sandstone, and Curtis formation. The Carmel formation consists of shale, limestone, sandstone, small amounts of gypsum, and conglomerate in thin and thick lenticular beds. Above the Carmel formation is the Entrada sandstone, a series of fairly thin, regular strata of sandstone interbedded with thicker sandstones and subordinate layers of calcareous and gypsiferous shale, gypsum, and limestone; the cementing material is gypsum and calcium carbonate, very rarely iron. The Curtis formation is composed of gypsum,

limestone, calcareous sandstone, and gypsiferous, strongly sandy shale. The thickness of the San Rafael group is about 500 feet in the Bryce Canyon area. The Winsor formation is a distinctive red- and white-banded sandstone about 600 feet thick. The Winsor formation is the oldest formation shown on the geologic map (fig. 8) accompanying this report.

Lower Cretaceous rocks are absent in the Bryce Canyon area. The Upper Jurassic Winsor formation is overlain by the Upper Cretaceous Dakota sandstone. The latter consists of irregularly bedded buff-gray medium- to coarse-grained sandstone in which are incorporated lenticles of shale, conglomerate, and coal. The Dakota sandstone has an average thickness of about 30 feet, but it ranges from 6 to 80 feet in thickness in the Paunsaugunt region. The Tropic shale is a blue-gray marine and brackish-water shale with interbedded buff sandstones, thin gypsum beds, and a few coal beds, and it has a thickness of about 800 feet. The Straight Cliffs sandstone is a sequence of sandstone and shale. The sandstone is mostly medium to coarse grained, but there are some conglomerate lenses. Concretions and nodules of iron are common, and blue-gray shale lenses resembling the Tropic shale also occur. The Wahweap sandstone lies in gradational contact on the Straight Cliffs sandstone. Fine to medium sand is the dominant rock of the Wahweap sandstone, and even the thin shale beds are very sandy. The combined thickness of the Wahweap and Straight Cliffs sandstones is more than 850 feet. The highest unit in the Upper Cretaceous series is the Kaiparowits formation,

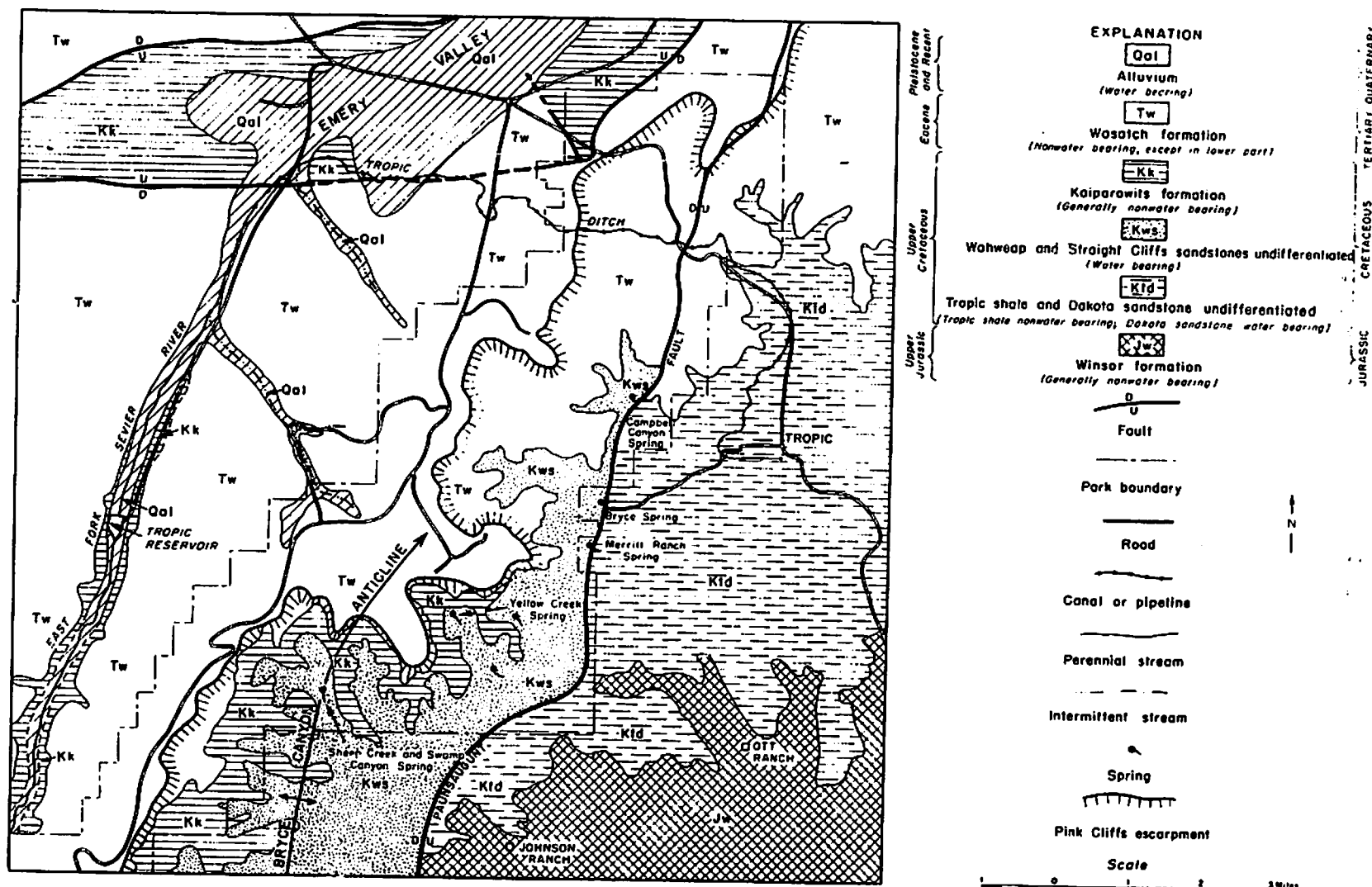


Figure 8. Geologic map of the northern part of Bryce Canyon National Park area, Utah.
(Modified from Gregory, H. E., 1951)

consisting of medium- to coarse-grained arkosic sand cemented by calcium carbonate and minor amounts of gypsum and iron oxide. It also includes brown, white, and greenish limestone and blue sandy, calcareous shale. Ironstone concretions, limestone concretions, chert, barite, and gypsiferous mudstone are minor constituents. The Kaiparowits formation is about 400 feet thick.

Cenozoic rocks

Tertiary system.-- The only Tertiary formation in the Bryce Canyon area is the Wasatch formation of Eocene age. Gregory (1951, p. 44-45) divided the Wasatch formation of the Paunsaugunt Plateau into three units: (1) At the bottom is a basal conglomerate that lies unconformably on the Kaiparowits formation. This unit contains pebbles of white quartz, black and gray chert, and red limestone; at some places sandstone that contains minor lenses of shale replaces the conglomerate. The conglomerate is 10 to 30 feet thick below Bryce Point and is present at the Tropic reservoir on the East Fork of the Sevier River, but it is absent in the Swamp Canyon and Yellow Creek area. The basal conglomerate, where present, is porous and carries ground water.

(2) In the middle is pink massive, thick-bedded limestone, the chief rock type displayed in the Pink Cliffs. Along with the pink limestone beds are white and gray sandstones and a few conglomerate beds.

(3) At the top is white to gray sandstone which forms the top of the Table Cliffs, north of the Bryce Canyon area, the top of Whiteman bench, and Boat Mesa but is absent over most of the Paunsaugunt Plateau. In addition to sandstone these "white beds" include conglomerate, siliceous limestone, and volcanic ash and tuff.

Quaternary system.-- Alluvial deposits floor the valleys of the East Fork of the Sevier River and its larger tributaries such as East Creek and Daves Hollow (figs. 2 and 8). The maximum thickness of alluvium on the plateau is found in Emery Valley, where it is reported to be about 136 feet (table 4). Washes cut through alluvial deposits which floor most of the valley areas below the rim. The age of the alluvium in both areas is in doubt. Part of it is certainly Pleistocene in age, and the rest is Recent.

Structure

The principal structural features of the Bryce Canyon National Park area are gently northeastward-dipping beds and several major normal faults. The regional dip of the beds ranges from half a degree to 3 degrees north, northeast, and east. Departures from the regional dip are found only in the immediate vicinity of faults and in gentle folds. A gently north-plunging anticline in the Willis Creek-Heward Creek vicinity was described by Hager (1957). The axis of this anticline is west of the Pink Cliffs escarpment in the Heward Creek area but crosses the escarpment in the vicinity of Sheep Creek.

Faulting is restricted to a few large-scale normal faults; two of these, the Paunsaugunt and Sevier faults, are regional in extent. The Sevier fault is about 7 miles west of the area covered by this report. These two faults trend northward and the east block of each fault is upthrown in relation to the west block. The Paunsaugunt fault does not coincide with the Pink Cliffs escarpment and, in fact, is not noticeable as a topographic feature of any kind. Two cross faults that trend generally eastward, connecting the Sevier and Paunsaugunt faults, are evident as topographic features -- fault-line scarps that form the borders of Emery Valley.

Each of these structural features exercises some control on the occurrence and movement of ground water in the bedrock aquifers of the area. Ground water moves through the rocks in the general direction of the regional dip, which accounts for the large number of springs along the eastern scarp of the Paunsaugunt Plateau. Along the Paunsaugunt fault springs occur where the eastward movement of ground water is blocked by upfaulted relatively impervious beds which force the water to rise to the surface. Tension fractures along the axis of the Bryce Canyon anticline (fig. 8) might create secondary permeability and afford an opportunity to obtain successful water supplies from wells penetrating the bedrock.

WATER RESOURCES

Surface Water

In the Bryce Canyon area there are only two perennial surface streams, the East Fork of the Sevier River and the Paria River, but short perennial reaches of tributary streams are fed by springs. The diversions of the Tropic and East Fork Irrigation Co. from the East Fork of the Sevier River into the Paria River drainage are shown in table 1. The U. S. Geological Survey gaging station was installed primarily to record the amount of water in the Tropic Ditch that crosses the divide; it does not necessarily record the total amount of water released from the Tropic Reservoir.

Springs

The springs of the Bryce Canyon National Park area may conveniently be divided into two groups: (1) those on top of the Paunsaugunt Plateau and (2) those below the rim in the Paria River drainage area. Fluctuations in the flow of springs on top of the plateau are closely related to annual precipitation, whereas fluctuations of the flow of springs below the rim are not. On the Paunsaugunt Plateau are two types of springs--bedrock springs and alluvial springs. The bedrock springs on the plateau may in turn be divided into those that issue from the "white beds" of the Wasatch formation and those that issue from the basal conglomerate of the Wasatch formation.

On the plateau several bedrock springs (for example, Shaker, Trough, and Whiteman) occur on the north and east sides of Whiteman Bench (see fig. 2). It is thought that these springs occur where permeable beds in the sandy "white beds" of the Wasatch formation lie in contact with the denser pink limestone beds of the same formation. Inasmuch as all the springs issue from thin alluvium, it is difficult to determine the bedrock source. These springs are recharged by rain and snow that falls on top and around the margins of Whiteman Bench, and the yields are unstable and fluctuate in response to variations in the amount and distribution of precipitation. In May 1957 Shaker, Trough, and Whiteman springs were not flowing. The upper graph in figure 3

shows that in 1956 the cumulative departure from normal precipitation was at the lowest point during the period of record, which probably accounts for the cessation of flow from the bedrock springs on the plateau.

Above the Tropic Reservoir on the plateau are numerous springs that contribute water to short tributaries of the East Fork (see fig. 2). The geologic map (fig. 8) shows that these springs issue from the Wasatch formation just above its contact with the underlying Kaiparowits formation. Gregory (1951, p. 46) stated that the basal conglomerate of the Wasatch formation is present near the Tropic Reservoir, and it is thought that the springs issue from this permeable bed. However, these springs were not visited by the writer.

Springs on the plateau whose source is alluvium are probably present in most of the larger valleys. Seven of these springs are present in East Creek valley (see fig. 9), and these were the only ones visited by the writer. These springs had an insignificant flow in May 1957, and by June all flow had ceased.

The second region of springs is below the rim in the Paria River drainage area, where springs issue from thin veneers of alluvium which obscure their bedrock source. The locations of these springs are shown in figure 2, and table 6 shows their altitudes, the geologic formations from which they issue, and their respective stratigraphic positions. The geologic formations and stratigraphic positions from which these springs issue were determined from

Gregory's geologic map (1951). Table 7 gives chemical analyses of water collected from selected springs.

Springs and seeps occur at many localities in the foothills below the rim on the east side of the Paunsaugunt Plateau. These are caused by the eastward and northeastward movement of water as it follows the dip of the more permeable beds. Sheep Creek, Swamp Canyon, Yellow Creek springs, and the springs farther south along the rim are examples of springs that owe their existence to the outcrop of permeable beds. Merrill Ranch, Bryce, and Campbell Canyon springs are fault-line springs. Figure 10 illustrates the mode of occurrence of most fault-line springs in this area. The upthrown block of Tropic shale forms a relatively impervious eastern barrier which forces water from the permeable beds in the Wahweap and Straight Cliffs sandstones to rise to the surface instead of continuing its northeastward movement.

Nearly all the springs below the rim issue from alluvium, although in some places bedrock is not far away, and the water emerging from these springs comes from a bedrock source. This conclusion is substantiated by their constancy of flow. If their source were the alluvium in the re-entrants, these springs probably would not flow in dry seasons, as there is generally insufficient alluvium to store enough water to support the flow except in wet weather. The recharge area of these springs is restricted to the Paunsaugunt Plateau and immediately adjacent areas. Formations below the Wahweap and Straight Cliffs sandstones probably

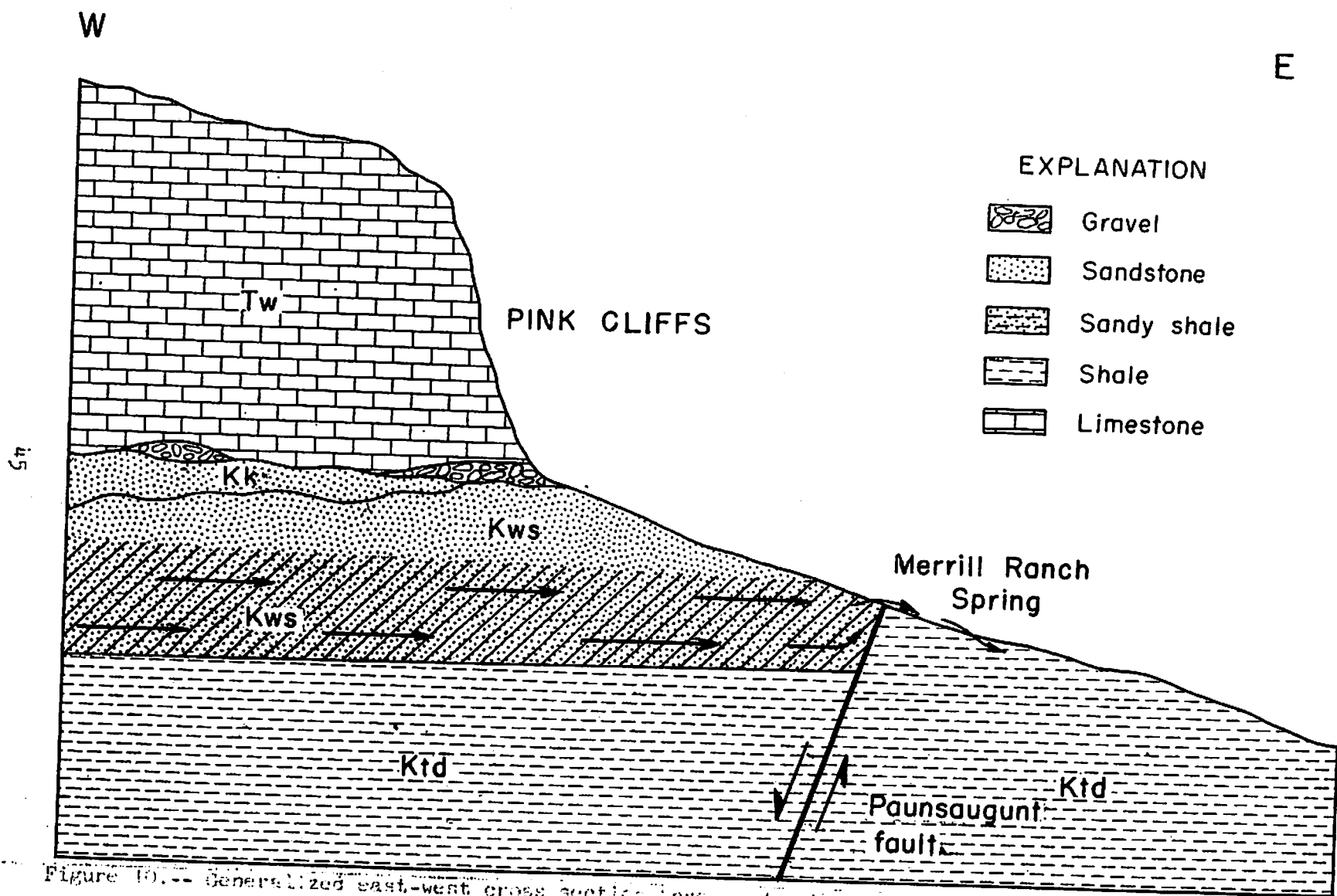


Figure 10.-- Generalized east-west cross section along the Merrill Ranch Spring showing the movement of ground water in relation to the occurrence of all fault-line springs in the area. Double-headed arrows represent direction of water movement; crosshatched area represents zone of saturation. Tw-Wasatch formation, Kk-Kaiparowits formation, Kws-Wahweap and Straight Cliffs sandstones undifferentiated, Ktd-Tropic shale and Dakota sandstone undifferentiated.

obtain part of their recharge from areas more distant than the plateau.

Table 6 shows the measured discharge of the springs below the rim in the Bryce Canyon area. Because the conditions at each spring are different, each will be considered separately with respect to its utilization for water supply. Springs north of Campbell Canyon were not visited by the writer, and no measurements of flow or chemical analyses are available.

Campbell Canyon Spring is within the National Park boundary and is 3 miles from the Utah Parks Co. storage tanks. Water rises in a grassy marsh between two washes that join just below the spring. The water drops about 10 feet from the grassy area to the gravel in the stream wash proper. Within 300 feet of the point where the spring water flows onto the gravel of the wash, all surface water has disappeared. Development work might increase the yield of this spring slightly (see table 3). The water is hard but otherwise of good quality (see table 7), and, like that of other springs below the rim, the yield is fairly constant. The principal objection to the development of a water supply at this site is the low yield of the spring (see table 6).

The Bryce Canyon Spring supplies drinking and culinary water to the town of Tropic. Residents estimate that the flow is about 1 cfs (cubic foot per second); however, the flow of the spring was not measured by the writer. Gregory (1951, p. 112) said that Tropic received 38 gpm from this spring area.

Merrill Ranch Spring is unique among the springs in the northern part of the Bryce Canyon area because it is not in a re-entrant in the Pink Cliffs but is $1\frac{1}{2}$ miles east of the Pink Cliffs along the Paunsaugunt fault (see fig. 10). The water rises in a grassy area, as does that of several of the other springs, but it does not empty into a gravel-bottomed wash as it does at the others. Sandy clay is at the surface in the source area for the spring, and this same sandy clay immediately underlies the area of discharge. Owing to the clayey nature of the surface material at the spring, it would be difficult to increase the yield of the spring substantially by development work. The yield is small (see table 6), and even a 50-percent increase would not provide enough water for the present water need of the Park.

Certain of the springs in Yellow Creek offer the best possibility for the development of a water supply from a spring source. The springs in Yellow Creek (fig. 2) have been subdivided for the purposes of discussion as follows: (1) Yellow Creek Spring (fig. 11); (2) Upper Yellow Creek Wash Spring; (3) a marshy area south of Yellow Creek but in the vicinity of (1) and (2); (4) Second Yellow Creek Wash Spring; (5) Right Fork (of Yellow Creek) Spring; (6) Third Yellow Creek Wash Spring.

The water from the Upper Yellow Creek Spring area (1 and 2) is of good chemical quality for domestic purposes (table 7), and the quantity is sufficient for the Park needs (table 6). An additional advantage of the Yellow Creek Springs source is the possibility of expansion as the need for water in the Park grows. The principal

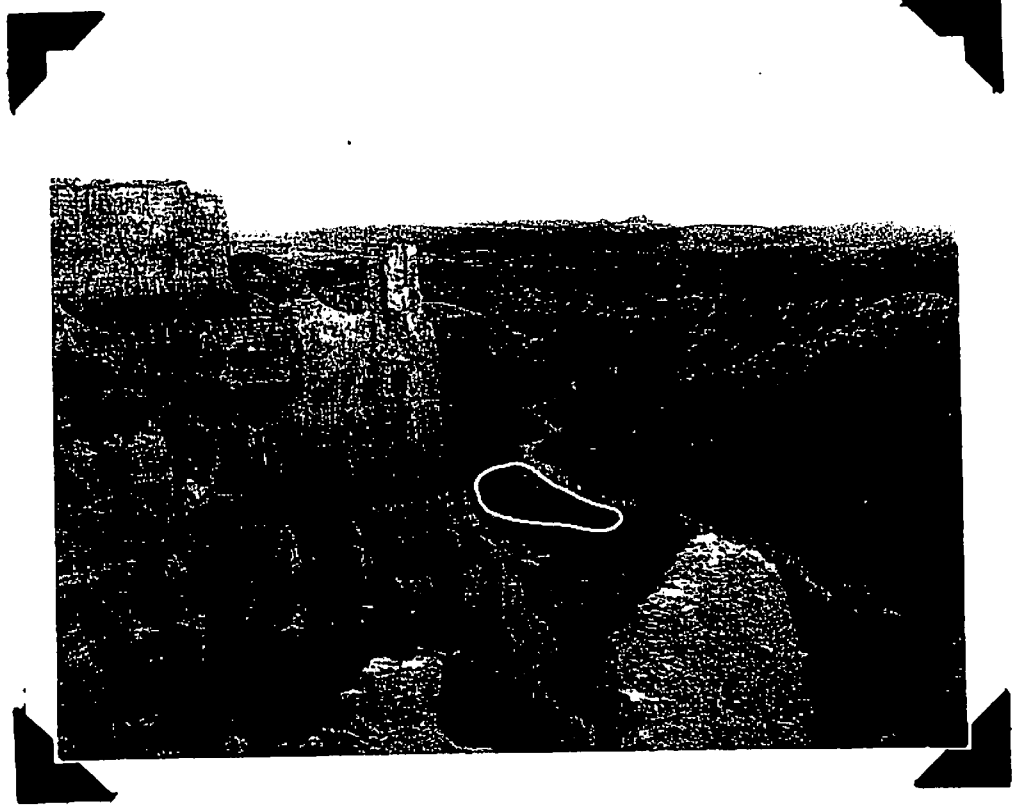


Figure 11.-- Yellow Creek Spring (circled) and Yellow Creek Wash seen from Paria View observation point.

disadvantage of the Upper Yellow Creek Springs source is that it is not readily accessible. The Upper Yellow Creek Spring area can be seen from the Paria View observation point (fig. 11), and it might be necessary to camouflage any structures placed there, so as not to spoil the view. A pipeline would have to be built to the top of the rim, but this would also be necessary for development of any of the spring sources below the rim.

Yellow Creek Spring (1) issues in a grassy marsh covering about 2 acres near the base of the Pink Cliffs. From this spring area the water drops about 10 feet into Yellow Creek Wash, where the water flows perennially. The relative positions of Yellow Creek Spring and Yellow Creek Wash are shown in figure 11. The water in the wash (2) first appears opposite the upper end of the spring area and probably comes from the same permeable bed in the Wahweap and Straight Cliffs sandstones that supplies the spring. On the south side of the wash is another grassy marsh (3) which suggests an additional outcrop of this permeable bed in the Wahweap and Straight Cliffs sandstones. Although this area is soggy and wet, no visible flow leaves it.

Inasmuch as the measured flow of Upper Yellow Creek Spring and Upper Yellow Creek Wash Spring (see table 6) represents only the water at the surface, it is probable that more water could be obtained by proper development work at this source. A substantial part of the water flowing at the surface in the permeable gravel wash must be sustained by underflow. It is possible that construc-

tion of a tile drain under the channel would make available additional water. If constructed in the wash proper, any surface works would be subject to destruction by the occasional, but violent, cloudburst floods that are responsible for emplacing the boulders and cobbles that make up the floor of the wash. Any construction in gravel washes should be planned with the destructive nature of these storms in mind. It is believed that the amount of surface discharge in Yellow Creek combined with the increased amount available as a result of development work would be sufficient for the Park needs for a long time.

At the Second Yellow Creek Wash Spring (4) water appears in the permeable gravel of Yellow Creek Wash. Water from this point flows at the surface for more than 4 miles downstream where it is used at Otts Ranch. Water from the Right Fork of Yellow Creek (5) disappears into the permeable gravel about 150 yards upstream from the point where that wash joins the main Yellow Creek Wash, and it was here that the flow was measured. The source of this water was not seen by the writer, and the location of the spring shown on figure 2 was reported by a local resident. Farther down Yellow Creek Wash, water appears again (6) but is of very poor chemical quality (table 7).

Table 3 shows that there is sufficient water in the Upper Yellow Creek area to supply the Park needs. If the Upper Yellow Creek area is developed for a water supply, laying the pipeline for some distance northward before ascending the Pink Cliffs

might insure that the spring in the Right Fork of Yellow Creek (5) would be conveniently near the pipeline, should additional water be needed in the future.

The Sheep Creek Spring (fig. 2) rises from small amphitheaters in the alluvium of the stream. The Swamp Canyon Spring rises from a grassy marsh several acres in area. The water from Swamp Canyon Spring collects in a channel and flows for several hundred yards before it joins the water from Sheep Creek. The yields from these two spring sources were measured separately a few score feet above their junction (see table 6). Development work at Swamp Canyon Spring probably could increase the yield, but it is doubtful if much could be done to increase the yield of Sheep Creek Spring. The proximity of these springs and the presence of similar chemical constituents in water derived from them indicate that both springs have a common bedrock source in the Wahweap and Straight Cliffs sandstones. The high sulfate and calcium contents are noteworthy and strongly suggest that abundant gypsum (CaSO_4) is present in the aquifer (see table 7). The high content of calcium and sulfate in this water makes it undesirable for a public water supply, although this spring area is probably the most accessible of any below the rim. These springs can be reached by jeep from the lodge and headquarters area. About 1 mile downstream from Sheep Creek Spring, on the side of a hill on the east slope of Sheep Creek valley, is a seep area called the Second Sheep Creek Spring in table 6 (fig. 2). This spring issues from the Wahweap and Straight

Cliffs sandstones and is unique in that alluvium does not obscure its bedrock source.

Springs south of Sheep Creek were not considered as possible sources of water for the lodge and headquarters area because of the availability of adequate water supplies nearer the area of use.

Ground Water in Alluvium

The area on the Paunsaugunt Plateau underlain by saturated alluvium is small compared with the area underlain by saturated bedrock. However, owing to the greater permeability of alluvium, these areas are of relatively great importance to the water resources of the region. In the Bryce Canyon area, the most significant deposits of alluvium occur beneath the valley bottoms of Emery Valley, the East Fork of the Sevier River, East Creek, Daves Hollow, and smaller tributaries to the East Fork.

East Creek Valley

In the summer of 1957 the water supply for Bryce Canyon National Park was obtained first from one well (well 1) and later from two wells (wells 1 and 2) in East Creek valley near the alluvial springs formerly used for a water supply. In order to determine if the water yield of this valley were sufficient for the Park needs and if the valley could support a larger development than now exists, greater emphasis was placed on investigating the ground-water resources of the alluvium in this valley than was given to other bodies of alluvium. This valley is in a favorable location because it is only a little more than 2 miles from the Utah Parks Co. storage tanks and because the pumping lift is only 372 feet.

Because of present and earlier water-supply developments in East Creek valley, more information was available on the quantity and dependability of the water yield from this alluvial body than from others. Information on the present water-supply developments in East Creek valley is included in the Water Use section of this report.

The flow of East Creek, when not caused by ephemeral cloud-burst storms, is controlled principally by the ground-water level in the adjacent alluvium. Springs and seeps occur only when the amount of water in the alluvium of East Creek valley is in excess of the amount required for saturation and for supplying those water using plants which are abundant in areas of high water table.

When sufficient water is released to the surface, it will start to flow down East Creek. In late summer 1955 and in 1956 and 1957 East Creek did not flow, suggesting that the alluvium in the valley was not saturated to the extent that it had been in previous years.

The cessation of flow in East Creek was due principally to a deficiency of precipitation during recent years. The upper graph of figure 3 shows the cumulative departure from normal precipitation at Bryce Canyon National Park for the period 1933 through 1956. According to the U. S. Weather Bureau the normal annual precipitation at Bryce Canyon National Park is 17.34 inches. The cumulative deficiency during the period from 1947 through 1956 amounted to about 33 inches, nearly 2 years' normal supply. It is not known how much effect this deficiency has had on the amount of water stored in the alluvium in East Creek valley, but the effect must have been substantial.

Some of the recharge to the alluvium comes from bedrock springs. Whiteman Spring, at the toe of Whiteman Bench, is tributary to East Creek, and when the spring flows it supplies some recharge to the alluvium along that stream. Fluctuations in the flows of Whiteman Spring and other bedrock springs on the Paunsaugunt Plateau probably bear a closer relation to the cumulative departure from normal precipitation than they do to the yearly precipitation. Whiteman Spring was dry in the summer of 1957; therefore, it contributed no recharge to the alluvium of East Creek valley. Although 1957 was a year of above-normal precipitation, several such years may be required to restore the flow of Whiteman Spring to its former normal volume.

A water-level recording gage was in operation on Utah Parks Co. well 3 from April 26, 1957, to October 23, 1957 (fig. 6). The hydrograph of this well shows that the water level in the alluvium of East Creek valley continued to decline as long as water was being pumped from the basin, indicating that the withdrawal exceeded the recharge. This is substantiated by the reaction of the water level to intermittent pumping in May 1957. The water level recovered when the pump was turned off, but not to the original static water level.

In order to determine how much water is stored in the groundwater reservoir in the alluvial valley, the flat valley floor, herein considered to represent the part of the valley underlain by alluvium, was mapped (see fig. 9 A). The slopes of the sides of the valley also were measured at selected points. In constructing the cross sections of the valley fill it was assumed that the slopes of the valley sides persist beneath the alluvium (fig. 12). Figure 13 was constructed by combining the cross sections of figure 12 with the section of figure 9 B. It is believed that the resulting geometric figures are representative of the approximate shape and dimensions of the alluvial fill.

On the assumptions that: (1) about 32 percent of the alluvium is water bearing (average in wells 1-3; see table 4); (2) the specific yield (drainable pore space) of the water-bearing material is about 20 percent; and (3) the total volume of saturated alluvium is about 40 million cubic feet (volume of shaded parts of figure 13) the volume of ground water in storage in the alluvium between cross sections A-A' and C-C' is estimated to be about 2.6 million

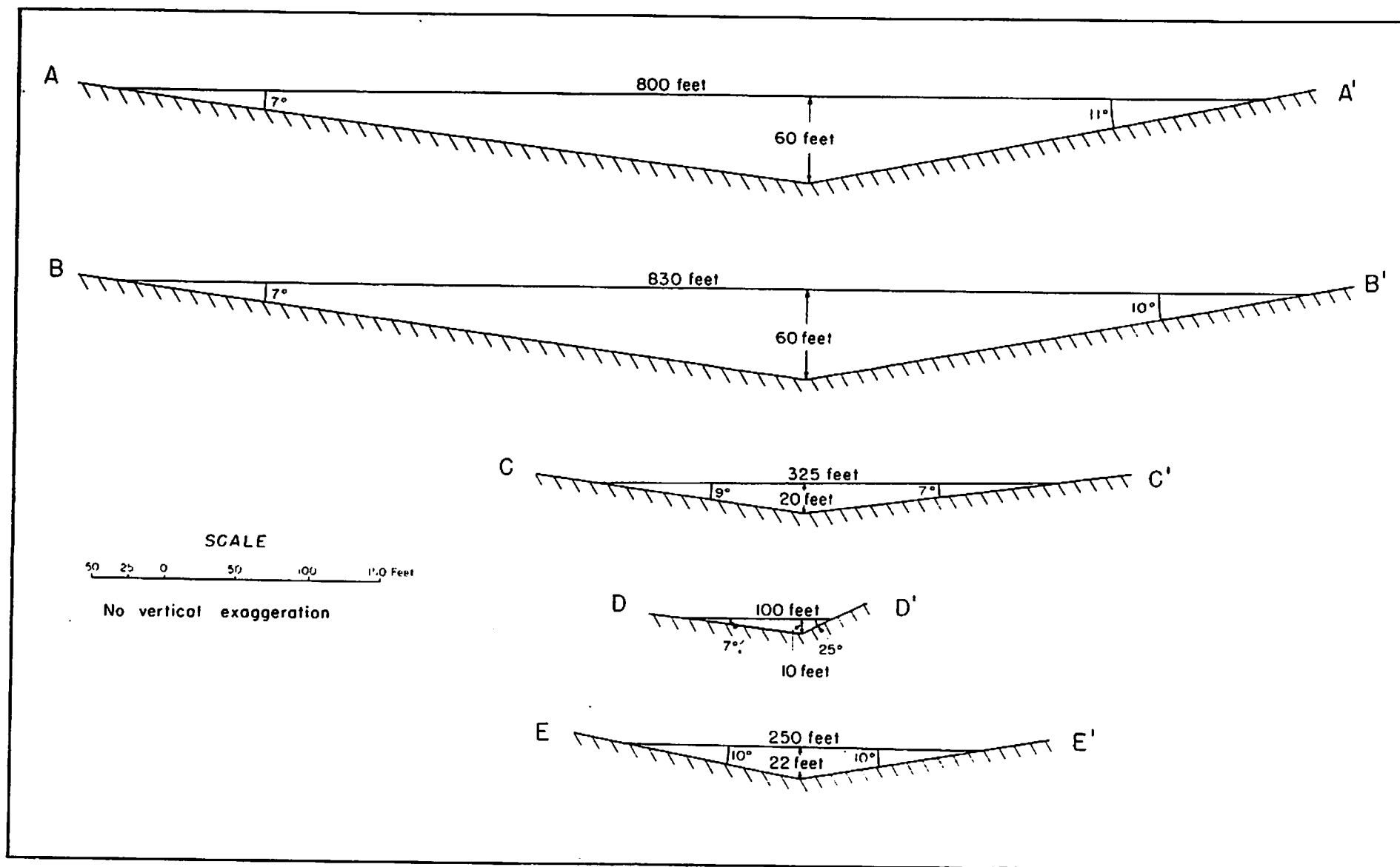


Figure 12. Selected schematic cross sections across East Creek valley showing approximate thickness of alluvium. The locations of the cross sections are shown on figure 9.

cubic feet. This amount of water might be available to a well that penetrated 60 feet of alluvium, that was equipped with a pump whose bowls were set at the bottom of the well, and that was pumped long enough. None of the Utah Parks Co. wells were drilled through as much as 60 feet of alluvium.

The ground-water storage available to the Utah Parks Co. wells may be estimated by subtracting the volume of ground water in storage below 25 feet in depth (about 1.2 million cubic feet) from the total storage in East Creek valley. The total volume of ground water available to the Utah Parks Co. wells as of May 1957 thus amounted to about 1.4 million cubic feet.

In this estimate it is assumed that the water table in the alluvium could be lowered in successive stages without the formation of excessively deep cones of depression. In late summer 1957 the cones of depression around both the existing wells were steep, and because of this circumstance it was not possible to develop the maximum amount of water from storage.

A chemical analysis of the water from well 1 is shown in table 7. This water is of very good chemical quality, and it is likely that water of comparable quality would be obtained wherever it was derived from the alluvium of East Creek valley.

Other Alluvium-Filled Valleys

Ground water probably occurs in the valley of the East Fork of the Sevier River under conditions very similar to those of East Creek valley. Because the drainage area of the East Fork is larger and the volume of alluvium in this valley is larger, the yield of ground water from the East Fork valley would probably be more dependable than that from East Creek valley.

Because the drainage area of Daves Hollow (about 5.4 square miles) is about half that of East Creek (11.2 square miles, of which about 9.3 square miles is above the pumphouse), the ground-water yield would probably be less dependable than that from the alluvium of East Creek valley. The yields of wells drilled in Emery Valley are small, suggesting that the water-bearing material is not highly productive. The total ground-water storage of this valley may be large, however.

Ground Water in Bedrock

The water-bearing properties as well as the geologic characteristics of the Cenozoic and Mesozoic formations that underlie the Bryce Canyon area are shown in table 5. The principal bedrock units that might yield water to a well, from the surface down, are:

(1) the basal conglomerate of the Wasatch formation, (2) the Wahweap and Straight Cliffs sandstones, (3) the Dakota sandstone, (4) parts of the Winsor formation, (5) the Entrada sandstone, (6) the Navajo sandstone, and (7) the Shinarump member of the Chinle formation.

The basal conglomerate of the Wasatch formation (1) is lenticular and might be missing at any particular place. A well drilled into the basal Wasatch in the vicinity of Bryce Point, where Gregory (1951, p. 46) reported the conglomerate to be 10 to 30 feet thick, might be successful, but there is no evidence concerning yields that might be expected. Even if a permeable lens of coarse material were penetrated, it might not be extensive enough to yield water perennially.

The Wahweap and Straight Cliffs sandstones (2) support many springs in the area, and in the Yellow Creek vicinity these sandstones yield water in large quantity. Most of the springs issuing from the Wahweap and Straight Cliffs sandstones supply excellent drinking water, but water from Swamp Canyon and Sheep Creek springs has a high sulfate content (table 7). It is entirely possible that a well drilled into the Wahweap and Straight Cliffs sandstones might encounter water of similarly poor quality.

The Dakota sandstone (3) is thin and for this reason would not be expected to yield large quantities of water. Because the overlying Tropic shale contains abundant gypsum, water from the Dakota sandstone probably would be high in dissolved minerals owing to seepage from above.

It is likely that water from the Winsor formation (4) also would be appreciably mineralized owing to the gypsum contained in the formation.

Water from the Entrada sandstone (5) probably is somewhat mineralized because of the presence of abundant gypsum in this formation, and yields would probably be small.

The Navajo sandstone (6) is 1,200 to 1,800 feet thick and perhaps thicker, and the minimum depth to the top of the formation is about 3,800 feet. Water from the Navajo sandstone might be of good quality because the sandstone is made up dominantly of quartz sand. The Navajo sandstone might yield water in sufficient quantity to supply the needs of the Park.

Water from the Shinarump member of the Chinle formation (7) is probably highly mineralized in this area and could be obtained only by drilling a well 6,500 feet or more deep.

Conclusions about the quality of the water in the foregoing formations are supported by an electric log of one oil test in the area.

If a bedrock test well is attempted it is recommended that it be drilled to the top of the Tropic shale at a depth of about 2,000 feet, in order to test the entire section of the Wahweap and Straight Cliffs sandstones. Because these are marine sandstones, permeabilities are probably fairly uniform but relatively small under most of the area in which a deep well would be drilled. Any bedrock test well should be located as far as practical from the ground-water discharge area below the rim. In addition, a site should be selected where there is a favorable opportunity to intercept fracture zones in the Wahweap and Straight Cliffs sandstones. The axis of the anticline described by Hager (1957), if extended, passes through Bryce Canyon, although the Bryce Canyon area is beyond the limits of his map. It is therefore recommended that any bedrock test well be located near the crest of this anticline so that the greatest number of tension fractures will be encountered. The location of a recommended test site is shown on figure 2.

It would seem that the chances of obtaining good water between the base of the Wahweap and Straight Cliffs sandstones and the Navajo sandstone are small. Therefore, unless it is intended to drill to the Navajo sandstone, at a depth of about 3,800 feet below the surface at the test site indicated on figure 2, there seems to be little reason to drill below the base of the Wahweap and Straight Cliffs sandstones. Several water-producing sands should be penetrated by a well drilled through the Wahweap and Straight Cliffs sandstones, but whether the yield of such a well would be sufficient for Park needs depends on the amount of fracturing in these formations.

CONCLUSIONS

The Bryce Canyon National Park needed about 1.3 million cubic feet of water for about 250,000 visitors in 1957 (table 3). According to the "MISSION 66" estimate, water facilities will have to be provided for about 500,000 visitors (fig. 1). For purposes of evaluating water sources, a hypothetical future requirement of about 5 million cubic feet of water per season was used.

Possible sources of water for the Park facilities include:

(1) surface water from the East Fork of the Sevier River, (2) water from wells in alluvium in the valley of the East Fork or in East Creek valley, (3) water piped up from springs below the Pink Cliffs, and (4) water from one or more wells drilled into bedrock.

Wells in the alluvium of East Creek valley could be an important source of water but not the sole source of water for the Park. Although the potential quantity available is small, the quality of the water is good and quite satisfactory for all uses in the Park. The low pumping lift to the Utah Parks Co. storage tanks (372 feet) makes this source of water a very desirable one. Sufficient water is available from this source to meet all but peak tourist-season needs; during periods of peak demand an additional source would be needed.

Of the springs below the Pink Cliffs, only springs in the Yellow Creek area need be considered, because others are lacking in either yield or quality. The Yellow Creek springs are dependable and yield water satisfactory in quality and adequate in quantity to supply all water needs created by any foreseeable expansion of the Park.

A well drilled to the top of the Tropic shale (about 2,000 feet) should penetrate one or more aquifers in the Wahweap and Straight Cliffs sandstones, and perhaps one at shallower depth at the base of the Wasatch formation. A well drilled on the plateau about $1\frac{1}{2}$ miles northwest of Yellow Creek Spring (see fig. 2) would lie near the axis of an anticline and might penetrate rock made relatively permeable by tension cracks.

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