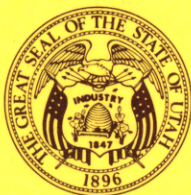


WATER - RESOURCES BULLETIN 8
1966

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY
affiliated with
THE COLLEGE OF MINES AND MINERAL INDUSTRIES
University of Utah, Salt Lake City, Utah

SECOND RECONNAISSANCE
OF WATER RESOURCES
IN WESTERN KANE COUNTY,
UTAH



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Directors:

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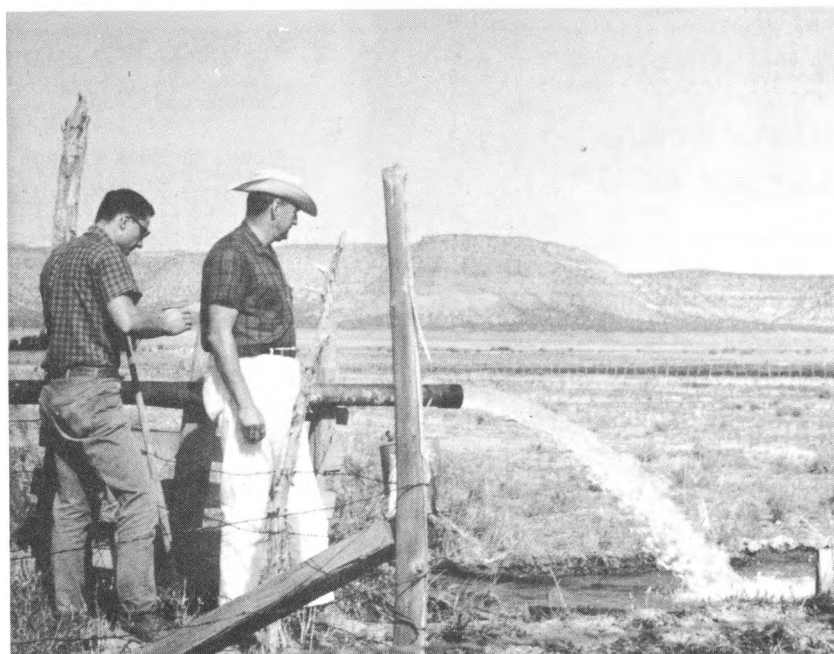
WATER - RESOURCES BULLETIN 8

SECOND RECONNAISSANCE

OF WATER RESOURCES

IN WESTERN KANE COUNTY, UTAH

*by Harry D. Goode
Department of Geology
University of Utah*



Well flowing about 350 gallons per minute, mouth of Johnson Canyon. James Carley and Dwain Haacke of U. S. Department of Agriculture are observing flow. (Reference No. 108 on figure 2 and table 3.)

**The field work for this study supported by
the Uniform School Fund of the University of Utah**

WATER-RESOURCES BULLETIN 8

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AUGUST, 1966

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

CONTENTS

	Page		Page
Abstract	5	Drainage of Johnson Canyon (cont.)	
Introduction	5	Seeps Wash	26
Purpose and scope	5	Drainage of Kaibab Gulch	26
Location, method of investigation, and plan of the report	6	Slide Canyon	26
Numbering system used to identify springs and wells in Utah	7	Meadow Canyon	26
Acknowledgments	7	Crawford Canyon	26
Water resources	8	Riggs Creek (Lower Podunk)	27
General geology and hydrology	8	Kitchen Corral Wash	27
Relation of geology to springs, surface water, and ground water	8	Drainage of the Paria River	27
Springs and surface water	8	Willis Creek	27
Drainage of East Fork of Virgin River	9	Hackberry Creek	27
Yellowjacket and Harris Springs	15	Cottonwood Creek	28
Drainage of Kanab Creek	15	Floods on Rock Springs Creek and on Willis Creek	28
Cottonwood Canyon and tributaries (west of Kanab)	15	Flood of July 24, 1964 on Rock Springs Creek	28
Lower Kanab Creek	16	Flood on Willis Creek	29
Drainage of Johnson Canyon	17	Ground water	29
Upper Johnson Canyon	17	Summation of storage and recharge	29
Thompson Wash	17	The principal aquifers	29
Skutumpah Canyon and Mill Creek and tributaries	17	Springs as indicators of saturated aquifers .	30
Mill Creek	17	Storage in and recharge to the Navajo Sandstone	31
Tennys Meadow	18	Storage	31
Lower Johnson Canyon	18	Recharge	32
Meadow Canyon	18	Wells	35
Dairy Canyon	18	Proposed withdrawals and their effects ..	35
Rock Canyon and east side of Johnson Canyon	18	Chemical quality of water from springs and wells	40
Needle Rock Canyon and west side of Johnson Canyon	19	Future development of ground water	42
Spring? near mouth of Johnson Canyon	19	References	42
Johnson Lakes Canyon	19	Glossary	43
Upper Johnson Lakes Canyon	19	Abbreviations and definitions of units of measurement	43
Lower Johnson Lakes Canyon and Flood Canyon	19	Definitions of hydrologic terms	43

ILLUSTRATIONS

	Page		Page
Frontispiece		Well flowing about 350 gallons per minute near mouth of Johnson Canyon ...	1
Figure			
1	Index map	4	
2	Map showing selected springs and wells, areas of proposed ground-water development, and normal annual precipitation	22	
3	Numbering system for springs and wells	7	
4	Regional map of Kanab and Kaiparowits coal fields, and showing also areas underlain by Navajo Sandstone and by other Jurassic rocks	15	
5	Sketch showing how water in stream channel is at surface in areas underlain by shale but sinks below in areas underlain by sandstone	16	
6	Sketches showing effect of leaks on spillover of tilted barrels left out where rain can fall on them	30	
7	Sketch showing relation of a spring to water table in a dipping aquifer	31	
8	Block diagram showing a canyon breaching a body of ground water	32	
9	Generalized geologic section approximately along Kanab Creek in Range 6 West	32	
10	Schematic diagram to show that pumping of distant wells will not affect spring flow..	37	
Plate			
1-A	Natural Bridge in Bryce Canyon National Park	20	
B	Town of Alton and Pink Cliffs on west side of Paunsaugunt Plateau	20	
		Plate (cont.)	
		C	Vermilion Cliffs, White Cliffs, and Pink Cliffs from Kaibab Plateau 20
		2-A	Canyon of lower Kanab Creek 21
		B	Kanab Creek near US 89 21
		C	Elkheart Cliffs along Sevier Fault east of Mt. Carmel 21
		3-A	Johnson Lake from northeast 24
		B	Johnson Lake from southwest 24
		C	Pipeline carrying spring water from Lamb Point Tongue to Fredonia, Arizona 24
		4-A	Flood of July 24, 1964 on Rock Springs Creek 25
		B	Same flood about 2 miles downstream from A 25
		Table	
		1	Principal geologic formations of western Kane County and their water-bearing properties 9
		2	Records of selected springs in western Kane County, Utah 10
		3	Records of selected wells in western Kane County, Utah 34
		4	Drillers' logs of selected wells in western Kane County, Utah 36
		5	Chemical analyses of 48 samples of water from 36 springs, 1 creek, and 3 wells 38
		6	Comparison of chemical analyses of water from the Kaiparowits, Wahweap, Straight Cliffs, and Navajo Formations 41

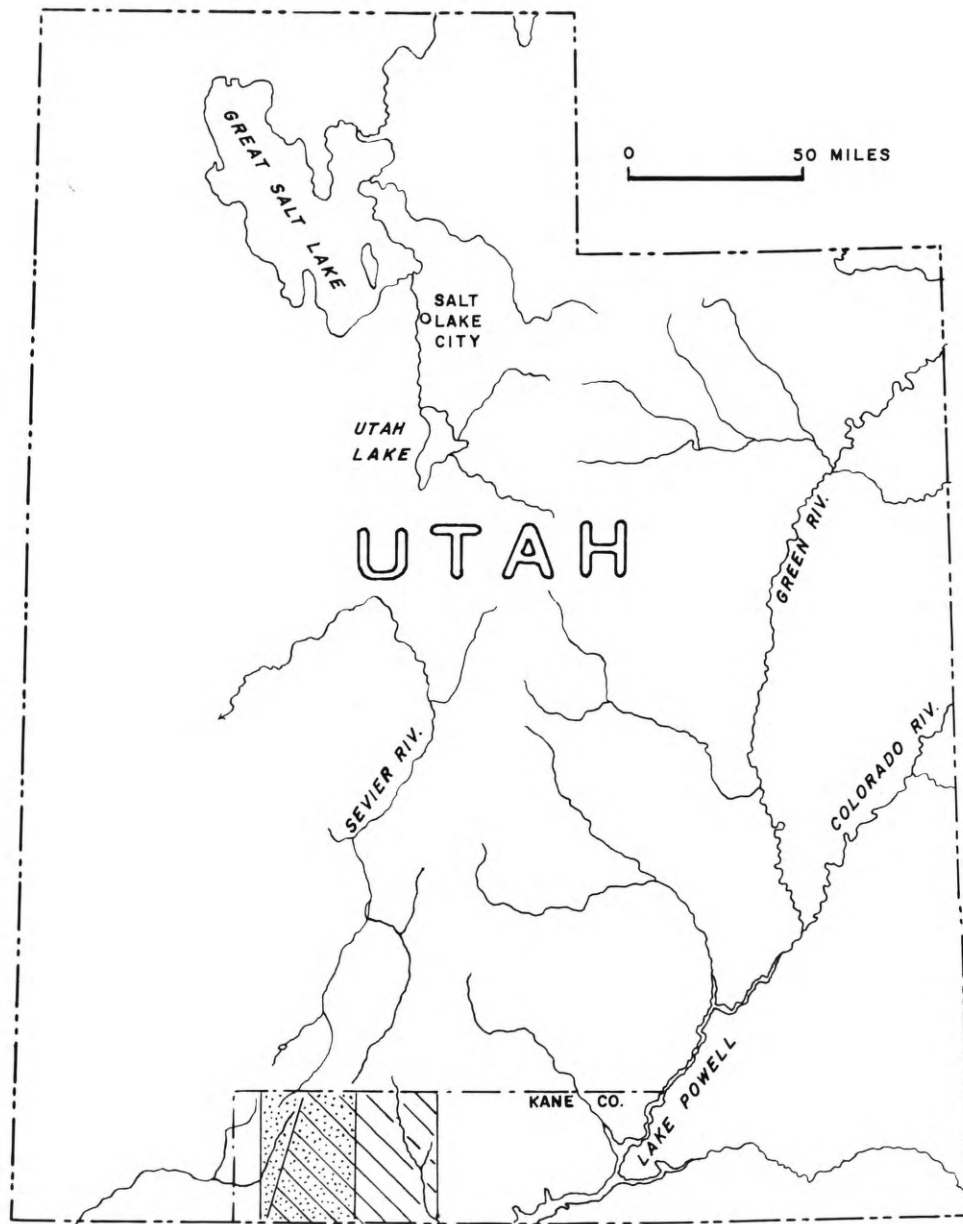


Figure 1. — Index map of Utah showing area discussed in this report (lined) and area covered by Water-Resources Bulletin 5 (stippled). The northern part of the area of overlap is covered in more detail in Bulletin 5; the southern part in more detail in this report.

SECOND RECONNAISSANCE OF WATER RESOURCES IN WESTERN KANE COUNTY, UTAH

by Harry D. Goode ^{1/}

ABSTRACT

This report supplements the studies reported in "Reconnaissance of Water Resources of a part of western Kane County, Utah," which was published by the Utah Geological and Mineralogical Survey and Utah Water and Power Board as Water-Resources Bulletin 5. Both studies were concerned with collecting and compiling information on water resources that would be useful in planning development of the huge coal deposits of the area. Power plants that would convert the coal into electricity would require 15,000 to 30,000 gallons per minute of water for each million kilowatts of power. One group of applications filed with the State Engineer in July 1964 asked for about 80,000 acre-feet per year to develop 2 million kilowatts of power.

This report confirms and extends the findings of Bulletin 5. The Navajo Sandstone probably contains on the order of 10 million acre-feet of water recoverable by wells less than 4000 feet deep, and, although the recharge to the Navajo is probably only 30,000 to 60,000 acre-feet a year over the 400 square miles of outcrop of the Navajo between the Salt Lake Meridian and the Sevier fault, the vast quantity now in storage should be sufficient to supply wells for many years to come.

The rocks of western Kane County range in age from Permian to Recent. The stratigraphic sequence is rather complete from the Kaibab Formation of Permian age to the Wasatch Formation of Eocene age (early Tertiary), and also includes rocks of Pleistocene and Recent age; but Tertiary sedimentary rocks younger than Wasatch are generally absent. This thick sequence is tilted northward to create a giant staircase structure that rises topographically and stratigraphically from south to north.

The principal supplies of ground water are in bedrock aquifers: in the Shinarump member of the Chinle; in the two members of the Navajo Sandstone; in the sandstones in the Upper Cretaceous formations; and possibly but not probably in the Wasatch. A few wells have yielded good supplies of water from the Shinarump at the mouth of Johnson Canyon and from the Navajo in Three Lakes Canyon, in Clay Flats, and in Johnson Canyon, but the strongest evidence for supplies of ground water in bedrock comes from springs, many of which issue from the rocks up dip, thus suggesting that they represent overflow from overfull aquifers down dip. Although there are many springs in the Upper Cretaceous rocks, the water-yielding beds in these rocks are probably thin and discontinuous, and therefore it is believed that the 2000-foot-thick Navajo Sand-

stone, which yields water in most canyons that cut down to its base, has the best potential for development. The base of this formation is 3000 to 4000 feet below the coal deposits in the area between the Sevier fault and the East Kaibab monocline.

Chemical analyses of water samples collected during 1963, 1964, and 1965 and other chemical analyses reported in Water-Resources Bulletin 5 show that: 1) water from springs in the Navajo Sandstone generally contains less than 250 ppm (parts per million) total solids and is hard to moderately hard (197 to 78 ppm hardness); 2) water from wells in the Navajo has been reported to have as much as 3100 ppm total solids, but generally has less than 900 ppm; 3) waters from springs in the Cretaceous sandstones contain 200 to 700 ppm total solids and are very hard (190 to 540 ppm hardness); and 4) waters from springs and wells in other formations contain 625 to nearly 1100 ppm total solids and generally are very hard (300 to 570 ppm hardness). Because the water from wells in the Navajo is generally of poorer quality than water from springs in the Navajo it is recommended that any test-drilling program to explore the Navajo include sampling the water to determine chemical suitability.

If the estimated 10 million acre-feet of water are in storage in the Navajo, such a reservoir could support annual withdrawals of 100,000 acre-feet for a long period despite the low annual recharge of 30,000 to 60,000 acre-feet. If this water were developed carefully so as not to infringe on existing rights it might be possible to put to use some of the coal deposits that otherwise could not be developed.

The basic data contained in this report include: records of 89 springs, records of 14 wells, drillers' logs of 9 wells, and 48 chemical analyses of spring, well, and surface waters.

INTRODUCTION

Purpose and Scope

The purpose of this study and the purpose of the study previously reported in Water-Resources Bulletin 5 (Goode, 1964) are the same: to study the water resources of western Kane County and to make available information on water resources that would be useful in planning the development of large generating plants which would produce electricity from the vast coal deposits of the area. Such plants commonly consume 15,000 to 30,000 gallons per minute (gpm) of water to produce 1 million kilowatts of power (Hill, 1965,

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p. 139); one plant proposed for the area of the Kanab coal field would produce 2 million kilowatts, and the proposers have applied to the State Engineer for permission to withdraw 110 cubic feet per second (about 50,000 gpm or 80,000 acre-feet per year) from the ground by wells.

Bulletin 5 reported that the Navajo Sandstone probably could be developed "by deep wells [that] might produce the largest quantities of water [compared to other underground sources] but at rather high cost" (Goode, 1964, p. 13); this report presents further arguments to support the evaluation that the Navajo should yield good quantities of water to wells, and it estimates that the amount of water in storage that can be reached by wells less than 4000 feet deep is probably 10 million acre-feet in the 1000-square-mile area underlain by the Navajo in western Kane County. A reservoir of underground water of about that size would be essential to the development of power in the coal fields -- such as the Kanab and western Kaiparowits -- that are remote from the water of Lake Powell.

This report presents the results of further reconnaissance during 1964 of water resources in western Kane County, Utah. The results of reconnaissance work done in 1963 were reported in Water-Resources Bulletin 5 (Goode, 1964); the results herein reported cover some areas in the southwestern part of Kane County that were sketchily mentioned in Bulletin 5 and also cover an appreciable additional area east of that covered by Bulletin 5 (fig. 1). This report, like its earlier counterpart, is not at all comprehensive; its conclusions are based on information gathered from about 80 springs and half a dozen wells and from a further evaluation of the data reported in Bulletin 5.

Location, Method of Investigation, and Plan of the Report

The area studied embraces most of western Kane County in southern Utah. The area shown on the map of figure 2 includes about 1800 square miles from the Salt Lake Meridian westward through about half of Range 8 West. The western half of this area was included on the geologic map in Water-Resources Bulletin 5 (Goode, 1964, fig. 3); and the studies of water resources reported in Bulletin 5 were concerned principally with the northern part of that area (the northwest quarter of figure 2, see center spread), or the area included in Tps. 38, 39, 40, and 41 S., Rs. 5, 6, 7, and 8 W.

This study investigated springs and wells in the rest of the area of figure 2 that could be reached in one-day traverses from roads. No investigations were made along the canyons occupied by Deer Spring Wash, Park Wash, or the middle reaches of the Paria River. The springs and wells that were visited were recorded on a map or on aerial photographs, the flows or yields of some springs and wells were measured or estimated, and the waters of some springs and wells were sampled for chemical analysis. I did the field work between July 19 and August 30, 1964, when I visited the areas by truck or on foot.

The yields of some springs and small streams were measured by bucket and stopwatch, by a 90° V-notch weir, or by a 3-inch Parshall flume. Standard tables were used to determine the flow through the weir and flume. The yields of many springs, especially those that feed flooded meadows, were not readily measured so their flows were estimated. Yields of single, free-flowing springs that could not be measured conveniently were estimated visually and may be in error by 100 percent; yields of large flooded-meadow areas were estimated by adding to the estimated or measured downstream yield of the areas a yield factor of 3 acre-feet per year per acre, which is the estimated amount of water required to keep meadows wet in areas where the evapotranspiration rate from flooded areas is 21 to 24 inches a year. (See Goode, 1964, p. 15-16 for a further explanation of the method used.)

Geologic field work consisted largely of attempting to identify the formation from which a spring was issuing; in this work the geologic map of the southwestern quarter of Utah (Hintze, 1963) was especially helpful.

Water samples for chemical analyses were collected in polyethylene bottles that were thoroughly rinsed in the water sampled. All samples were analyzed by the Utah State Chemist, of the State Department of Agriculture.

During the six weeks of field work it was necessary to be somewhat selective in choosing areas to be investigated. Existing topographic maps and aerial photographs were used to help select areas that appeared favorable for springs. Some areas, such as the regions cut by Deer Spring Wash, Park Wash, and the middle reaches of the Paria River, were not readily accessible to one man on foot and were not visited; these areas are in the driest parts of the region, however, and I doubt that they support springs that yield more than a few gallons a minute.

The presentation of the material in this report follows in part the plan set up in Water-Resources Bulletin 5. Springs and surface waters of the principal drainages are discussed in downstream order, and the drainages are discussed from west to east. Because many of the springs and wells are in areas that are not covered by modern topographic maps -- and hence could not be given precise numbers according to the well-numbering system of Utah (see next section of this report for description of the system) -- all springs and wells and sampling localities are given reference numbers. These numbers appear on the map of figure 2 and in tables 2, 3, 4, or 5.

The emphasis in this report is on the Navajo Sandstone as an aquifer that has great potential for development. Therefore, although the tables contain appreciable information about springs, wells, and chemical quality of water in the Cretaceous sandstones and in other formations, the principal discussions of this report are concerned with the arguments for developing the Navajo Sandstone.

Numbering System Used to Identify Springs and Wells in Utah

The numbers used in this report to identify springs and wells in Utah indicate the spring or well location by land subdivision according to a coordinate numbering system that was devised cooperatively by the Utah State Engineer and G. H. Taylor of the U.S. Geological Survey about 1935. The system is illustrated in figure 3. The coordinate number used to designate location of a well or spring comprises letters and numbers that designate consecutively the quadrant and township (shown together in parentheses by a capital letter designating the quadrant in relation to the base point of the Salt Lake Base and Meridian, and numbers designating the township and range); the number of the section; the quarter section (designated by a letter); the quarter of the quarter section; the quarter of the quarter-quarter section; and, finally, the particular spring or well within the 10-acre tract (designated by a number). By this system the letters A, B, C, and D designate, respectively, the northeast, northwest, southwest, and southeast quadrants of the standard base and meridian system of the General Land Office, and the letters a, b, c, and d designate, respectively, the northeast, northwest, southwest, and southeast quarters of the section, of the quarter section, and of the quarter-quarter section. This coordinate number can be used to identify either wells or springs because it designates location, and the usage of the number

in the text or table will show whether the number refers to a well or spring. Thus, the expression, well (B-2-2) 12dcd-2, refers to well 2 in the $SE\frac{1}{4}SW\frac{1}{4}SE\frac{1}{4}$, sec. 12, T. 2 N., R. 2 W., the letter B showing that the township is north of the Salt Lake Base Line and the range is west of the Salt Lake Meridian; and, similarly, the expression spring (D-3-2) 34bca-1, refers to spring 1 in the $NE\frac{1}{4}SW\frac{1}{4}NW\frac{1}{4}$ sec. 34, T. 3 S., R. 2 E.

Acknowledgments

This study was wholly financed by Uniform School Funds administered through the College of Mines and Mineral Industries, University of Utah. Publication of the report was financed jointly by the Utah Water and Power Board and by the Utah Geological and Mineralogical Survey.

I am indebted to many residents of Kane County who guided me to springs or gave freely of their time to tell me about the water problems of the area. Among these are Mr. Lynn Findlay who showed me the wells and many springs on his property, Mr. W. L. Johnson who showed me his well and springs in and near Johnson Canyon, Mr. Alvin Judd who told me about the springs in Dairy Canyon, Mr. R.S. Bunting who told me about his irrigation well in Johnson Canyon, and Mr. Merle Adams who showed me the springs on the Frank Ghiglia property. I am especially indebted to Mr. Dwain Haacke of the U.S. Soil Conservation Service for his

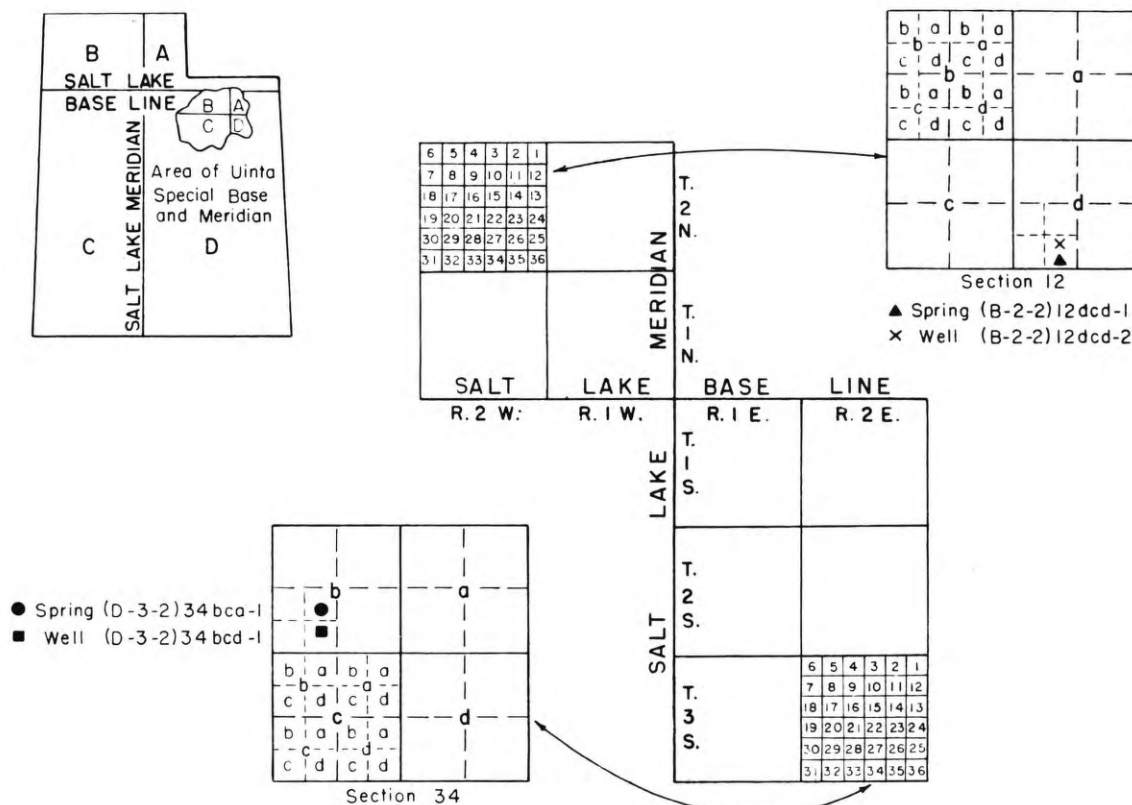


Figure 3. — Numbering system used to designate springs and wells in Utah.

help in taking me to the Fredonia springs in and near Cottonwood Creek and for showing me the artesian wells near the mouth of Johnson Canyon.

Several officials of Kane County gave their support to the investigation. Among these are Mr. W.R. Heaton, Kane County Assessor; Mr. Merrill MacDonald, Chairman, Kane County Commission; and Sheriff LaNard Johnson.

Two graduate students at the University of Utah helped with part of the field work: John Lawrence was most helpful with the investigations in the vicinity of Cottonwood and Hackberry Creeks, and Christopher Seibert collected several water samples in March 1965.

Dr. Ray E. Marsell of the Utah Water and Power Board critically read the manuscript and corrected many of the errors that appeared in it. I am greatly indebted to him also for suggestions and encouragement he gave me while I was preparing this report. Despite the help I received, I must take responsibility for the opinions that are expressed, and any errors that remain are wholly mine.

WATER RESOURCES

The water resources of western Kane County consist of springs, ephemeral and perennial streams, and large but imperfectly known quantities of water in storage in the ground.

Rainfall, which is the ultimate source of all the water in the area, is scanty over much of the region. In the vicinity of Kanab annual precipitation is about 12 inches, and precipitation increases northward as the land becomes higher. On the Paunsaugunt Plateau annual precipitation ranges from 20 to about 25 inches and on the Markagunt Plateau from 25 to more than 30 inches (fig. 2).

The geology of the area is the principal factor that determines 1) whether the precipitation that falls will flow across the land surface or sink into the ground, 2) where springs rise, and 3) the amount of water in storage in the ground; the first part of this discussion on water resources, therefore, will briefly describe the general geology and relate the geology to the hydrology of western Kane County.

General Geology and Hydrology

The rocks of western Kane County range in age from Permian to Recent. The sequence is rather complete from the Kaibab Formation of Permian age to the Wasatch Formation of Eocene age (early Tertiary), and also includes volcanic rocks of Pleistocene and Recent age

along with some surficial deposits of Recent age, but Tertiary sedimentary rocks younger than Wasatch age are generally absent. Table 1 lists the principal geologic formations and gives their lithology and water-bearing properties.

The rocks of western Kane County have gentle dips toward the north because they have been warped upward from the south. Cliff-forming sandstones and limestones alternate with slope-forming shales to create a giant staircase structure that rises stratigraphically and topographically from south to north (Plate 1-C). Near the Arizona border are the Vermilion Cliffs formed of Triassic rocks, and above them successively are the White Cliffs of the Navajo Sandstone and the Pink Cliffs of the Wasatch Formation (fig. 2). Offsetting this dipping structure are two northeast-trending, east-side-up, normal faults, the Sevier (Plate 2-C) and Paunsaugunt, and a fold structure, the East Kaibab monocline. The structure of the area can be interpreted from the generalized geologic map (fig. 4), which also shows the areas underlain by coal that occurs in the Cretaceous rocks in the Kanab and Kaiparowits coal fields, and from the generalized cross section (fig. 9), which shows the northward dip of the rocks in the vicinity of Kanab Creek.

Relation of Geology to Springs, Surface Water, and Ground Water

The springs, surface water, and ground water of western Kane County are all part of the total natural water system of the county. Water that issues from the ground as a spring becomes surface water as it flows over the ground and may later become ground water again as it sinks into porous material; still later the same water may return to the surface once again as a spring. The dipping sandstones and shales of Kane County promote this phenomenon of disappearance and reappearance of water, because the porous sandstones tend to absorb and store water whereas the shales tend to reject water. The sequence is illustrated and described in figure 5.

In the discussion that follows the springs and surface water are described first in considerable detail, for these occurrences can be seen; then the ground water is described from information inferred largely from springs, for there are few wells to supply direct information about ground water.

Springs and Surface Water

The springs and streams covered by this section are discussed in downstream order within drainages, and the drainages are discussed from west to east. Reference numbers from 1 to 94 are used to identify the springs and sample localities on figure 2 and in tables 2, 5, and 6. These reference numbers follow the order

Table 1. — *Principal geologic formations of western Kane County and their water-bearing properties.*

Age	Formation	Thickness in feet	Lithology	Water-bearing properties
Quaternary	Surficial deposits and lava	A few to 50 feet	Alluvial sand; dunes; basalt flows	Of local significance only--a few springs in basalt
Tertiary	Brian Head and Wasatch	500 to 1,000	White, red, and pink limestone and siltstone	Springs on plateaus and in steep cliffs; 50 to 500 gpm
Cretaceous	Kaiparowits, Wahweap, and Straight Cliffs	1,300 to 2,000	Interbedded sandstone, siltstone, and claystone. Straight Cliffs contains coal in Kaiparowits field	Springs occur at many contacts where sandstone is above and claystone below; 1 to 500 gpm
	Tropic and Dakota	500 to 1,300	Shale and coal over conglomerate	Springs 2 to 20 gpm in Sink Valley
Jurassic	Winsor, Curtis, Entrada	400 to 500	Fine-grained sandstone and gypsum	Probably not water bearing
	Carmel	150 to 200	Limestone and shale	Springs of 1 to 5 gpm of water of rather poor quality
Jurassic	Navajo, upper massive member (includes Gregory's Temple Cap Member)	1800 to 1500	Massive, cross-bedded, porous eolian sandstone	Springs yield a few to more than 200 gpm; wells 400 to 600 gpm
Triassic(?)	Tenney Canyon Tongue of Kayenta	100 to 200	Mudstone, siltstone, sandstone	Acts as a barrier to hold water in overlying Navajo
Triassic(?)	Lamb Point Tongue of Navajo	400 to 500	Massive, cross-bedded, porous eolian sandstone	Springs yield a few to more than 200 gpm; wells to 600 gpm
Triassic(?)	Kayenta	75 to 400	Mudstone, siltstone, sandstone	Acts as a barrier to hold water in overlying Lamb Point Tongue
Triassic(?)	Moenave	500	Siltstone and sandstone	Probably not water bearing
Triassic	Chinle (includes Shinarump and Petrified Forest Members)	500	Sandstone, conglomerate, siltstone, claystone	Sparse springs of a few gpm; wells to 350 gpm near mouth of Johnson Canyon
Triassic	Moenkopi	1000	Marine limestone; siltstone, gypsum	Probably not water bearing
Permian	Kaibab - Not investigated			

of discussion except that numbers 90 to 92 were applied to springs that were described in Bulletin 5, but whose waters were resampled for additional chemical analyses in 1964 and 1965; the numbers 90 to 92 thus appear at the top of table 5 but these springs are not further described.

Drainage of East Fork of Virgin River

The East Fork of the Virgin River drains a large area south of the Markagunt Plateau. The principal springs and tributaries that feed the East Fork north of Mt. Carmel Junction on U.S. Highway 89 were discussed

Table 2. — Records of selected springs in western Kane County, Utah.

Springs recorded here are in the drainages of East Fork of the Virgin River, lower Kanab Creek, Johnson Canyon, Kaibab Gulch, and Paria River. The records of this table supplement those of table 3, Water-Resources Bulletin 5.

Abbreviations used and further explanation of some columns in this table: * in any column = additional information in Remarks. No. = reference number used on base map and other tables. Sub-drainage: listed in downstream to upstream order. Spring number: see text for description of numbering system; some coordinates are approximate because topographic maps were not available. Approximate altitude: altitude from topographic maps in feet above mean sea level. Kind of rock: Ss (or ss) = sandstone; Cret = Cretaceous; Pet Forest Mem = Petrified Forest Member. Openings: springs are implied; seeps are so indicated. Flow: gpm = gallons per minute; pt = pint; qt = quart; < = less than; E = estimated; M = measured. Remarks: C = chemical analysis in table 5.

No.	Sub-drainage	Owner, name of spring, or further information	Topography	Spring coordinate number 1/ = approx.	Nearby town or reference point	Date of record	Approximate altitude	Kind of rock	Openings	Improvements, accommodations, or use of water	Flow	Temperature °F	Remarks or other data
DRAINAGE OF EAST FORK OF THE VIRGIN RIVER													
1	Yellowjacket Canyon	Yellowjacket # 1	Near top of mesa	(C-43-8) 1abc	Mt. Carmel Jct.	7/19/64		Navajo Ss *		Two steel troughs, one broken concrete trough	1 pt/min M	96 from pipe*	Rock: Base of Temple Cap Member or top of massive ss Temp: Ground temp. 131° C
2	Yellowjacket Canyon	Yellowjacket # 2		(C-42-8) 36ddc	Mt. Carmel Jct.	7/19/64	6170	Navajo Ss		Pipeline, two troughs	<1 qt/min M	74 at pipeline	
3	Rock Canyon	Harris Springs	Near head of canyon	(C-43-8) 9dbb & dbc	Mt. Carmel Jct.	7/19/64		Probably Navajo Ss	Two or more	Plastic pipeline from south spring	3 gpm E	No.spr. 67 So.spr. 73	C
DRAINAGE OF LOWER KANAB CREEK													
4	Cottonwood Canyon	Upper Cottonwood	West side, Cottonwood Can.	(C-43-7) 3ccb	Kanab	7/27/64	5840	Navajo Ss, massive		Trough	5 gpm E		
5	Cottonwood Canyon	Upper Cottonwood	West side, Cottonwood Can.	(C-43-7) 3ccd	Kanab	7/27/64	5820	Navajo Ss, massive	Many	Pond	25 gpm E		
6	Cottonwood Canyon	Upper Cottonwood	West side, Cottonwood Can.	(C-43-7) 3ccc	Kanab	7/27/64	5800	Navajo Ss, massive	One main, many seeps	Spring house	10 gpm E	55	C
7	Cottonwood Canyon	Upper Cottonwood	West side, Cottonwood Can.	(C-43-7) 10bbd	Kanab	7/27/64	5760	Alluvium *		Small ditch runs north	3-5 gpm E	55	Source is probably massive Navajo Ss
8	Cottonwood Canyon	Farm Canyon # 1	South side, Farm Canyon	(C-43-7) 9dbd	Kanab	7/27/64	5880	Navajo Ss, massive	Two	Pond and two ditches	18 gpm E 15 gpm M	54	C
9	Cottonwood Canyon	Farm Canyon # 2	Center of embayment	(C-43-7) 9dca	Kanab	7/27/64	5900	Navajo Ss	One		3 gpm E	55	
10	Cottonwood Canyon		Bottom of creek	(C-43-7) 15acd	Kanab	8/ 5/64	5490	Base of Lamb Point Tongue	Seeps	Flows to creek	15 gpm E		
11	Cottonwood Canyon	Water Canyon # 1	Bottom of canyon	(C-43-7) 21aab	Kanab	8/ 5/64	5540	Lamb Point Tongue	Several	None	10-15 gpm E	62	
12	Cottonwood Canyon	Water Canyon # 2	West side, Water Canyon	(C-43-7) 16ddd	Kanab	8/ 5/64	5520	Lamb Point Tongue	Many	Many collection galleries, pipeline	150 gpm E	58	C
13	Cottonwood Canyon	Scotty Corral	Box canyon east of Cottonwood Can.	(C-43-7) 14dcb	Kanab	8/ 5/64	5500	Base of Lamb Point Tongue	Seeps	Runs into wash	8-10 gpm E		
14	Lower Kanab	Headwaters	Bottom of Canyon	(C-42-6) 4cbc	Kanab	8/ 1/64	5380	Navajo Ss, possibly on fault	Several	Flows to creek	25 gpm E *	62	Yield reported as 300-400 gpm in W-R Bull. 5

No.	Sub-drainage	Owner, name or spring, or further information	Topography	Spring coordinate number 1/ = approx.	Nearby town or reference point	Date of record	Approximate altitude	Kind of rock	Openings	Improvements, accommodations, or use of water	Flow	Temperature °F	Remarks or other data
DRAINAGE OF LOWER KANAB CREEK - Continued													
15	Lower Kanab	Lower headwaters	East side, Kanab Creek	(C-42-6) 4ccc	Kanab	8/ 1/64	5360	Navajo Ss, possibly on fault	Many	Flows to creek	100 gpm E	58	C
16	Lower Kanab	Near mouth of Red Canyon - east side, Kanab Creek	East side, Kanab Creek	(C-42-6) 9bbd	Kanab	8/ 1/64	5340 *	Navajo Ss, massive	Several	Flows to creek	15 gpm E *	72	Yield reported as 200-300 gpm in W-R Bull. 5 Altitude reported as 5880 in W-R Bull. 5
17	Lower Kanab		West side, Kanab Creek	(C-42-6) 17aaa	Kanab	8/ 1/64	5280	Navajo Ss, massive	Many	Flows to creek, feeds meadow	50-100 gpm E		
18	Lower Kanab		West side, Kanab Creek	(C-42-6) 17aad	Kanab	8/ 1/64	5280	Navajo Ss, massive	Many	Flows to creek, feeds meadow	100 gpm E		
DRAINAGE OF JOHNSON CANYON													
19	Skutumpah Thompson Wash	Bald Knoll Hollow	Near head of small draw	(C-40-5) 11bd 1/	Skutumpah	8/25/64	6600	Cret ss over gray siltstone	Several	Stock & wildlife	2-3 gpm E	56	C
20	Skutumpah	Thompson	West side, Thompson Canyon	(C-40-5) 11ab 1/	Skutumpah	8/25/64	6600	Tan ss over gray Cret siltstone	Several	Overflow goes to primitive ditch	2½ gpm M	57	C
21	Skutumpah	Mill Creek, left fork west pink	Below Pink Cliffs	(C-39-5) 25db 1/	Skutumpah	7/28/64	8500	Probably Cret ss below Pink Cliffs			15-20 gpm E	*	65 at jct. with east pink
22	Skutumpah	Mill Creek, left fork east pink	Below Pink Cliffs	(C-39-5) 25da 1/	Skutumpah	7/28/64	8500	Cret ss, Kaiparowits	Several	None	30 gpm E	*	C; 55 about 200 ft from source. 63 at jct. with west pink
23	Skutumpah	Mill Creek, left fork	West side of canyon, 30-40 ft up side	(C-39-4½) 30bb 1/	Skutumpah	7/28/64		Cret ss	Many *	Feeds into creek	25-30 gpm E	49 near top of seeps	C; stretches about 100 yds on west side of canyon
24	Skutumpah	Mill Creek, left fork	East side of canyon	(C-39-4½) 30bc 1/	Skutumpah	7/28/64		Cret ss	Many seeps	Feeds into creek	10 gpm E	57-58	
25	Skutumpah	Mill Creek, jct. left & right forks	End of ridge	(C-39-4½) 31ab 1/	Skutumpah	7/29/64		Cret ss over shale	Seeps	Flows into creek	5 gpm E		
26	Skutumpah	Mill Creek, right fork - pipeline	Saddle on divide between N & S drainage	(C-39-4½) 17cb 1/	Skutumpah	7/29/64	8500	Wasatch		Pipeline, 2", about 1 1/3 mi long (abandoned)	1 pt/min E		
27	Skutumpah	Mill Creek, right fork	Beneath Pink Cliffs	(C-39-4½) 17cc 1/	Skutumpah	7/29/64	8500	Cret ss		Flows into creek	1 pt/min E		
28	Skutumpah Mill	Tennys meadow	East side, main valley	(C-39-4½) 29dd 1/	Skutumpah	7/30/64		Cret ss	Two	Pond, ditches	5 gpm E south 25 gpm E north	49	C (north)
29	Skutumpah Mill	Tennys meadow	Near base of ridge, west side of valley	(C-39-4½) 32dc 1/	Skutumpah	7/30/64		Cret ss	Seeps	None	5 gpm E		
30	Cottonwood Canyon, right fork	Timber Mtn.	North edge plateau, head of canyon	(C-41-4½) 34bbb		7/30/64		Navajo Sandstone		Stock	3/4 gpm M	55	
31	Johnson, Meadow	Johnson Mackelprang	Near middle of Meadow Canyon	(C-42-5) 25ccd & cdc	Kanab	8/28/64	5400	Alluvium *	Seeps				Probable source: Lamb Point Tongue
32	Johnson, Meadow	Meadow - east (Mackelprang)	East side, Meadow Canyon	(C-42-5) 36bbd	Kanab	8/28/64	5400	Lamb Point Tongue	Several		15 gpm E	57	C
33	Johnson, Meadow	W.L. Johnson	West side, Meadow Canyon	(C-42-5) 36bcb	Kanab	8/28/64	5360		Two or more		30 gpm E		

Table 2. — Records of selected springs in western Kane County, Utah . . . (continued)

No.	Sub-drainage	Owner, name of spring, or further information	Topography	Spring coordinate number 1/ = approx.	Nearby town or reference point	Date of record	Approximate altitude	Kind of rock	Openings	Improvements, accommodations, or use of water	Flow	Temperature °F	Remarks or other data
DRAINAGE OF JOHNSON CANYON - Continued													
34	Johnson	W.L. Johnson house spring	East side, Johnson Canyon	(C-42-5) 35adb	Kanab	8/28/64	5360	Lamb Point Tongue	Seeps	Collection box, pipeline	1/4 gpm E	*	C; 67° at house box
35	Johnson, Dairy	Alvin Judd house spring	North side, mouth Dairy Canyon	(C-42-5) 35bdb	Kanab	8/29/64	5360	Lamb Point Tongue		Collection box, pipeline	1/4 gpm E	65	
36	Johnson, Dairy	Dairy Canyon springs	Mouth of Dairy Canyon	(C-42-5) 35c & 34d	Kanab	8/29/64	5360	Lamb Point Tongue *	Many	Pond	200-450 gpm E	56	C (sampled at 35 cbd)
37	Johnson, Rock	Rock Canyon springs	East side, Johnson Canyon	(C-43-5) 1b	Kanab	8/29/64	5320	Lamb Point Tongue	Several	Pond (apparently not used)	None		*Possibly on fault
38	Johnson		East side, Johnson Canyon	(C-43-5) 1c	Kanab	8/29/64	5310	Lamb Point Tongue	Many for distance of 400 yds	Pond	100 gpm E		
39	Johnson, Needle Rock	Needle Rock Canyon springs		(C-43-5) 2b	Kanab	8/29/64	5350	Lamb Point Tongue	Several	Pond, feeds meadow	25-50 E		
40	Johnson	Frank Ghiglia	West side, Johnson Canyon	(C-43-5) 2db	Kanab	8/29/64	5300	Lamb Point Tongue	Many	Pond, SE corner	50 gpm E		
41	Johnson	Frank Ghiglia	West side, Johnson Canyon	(C-43-5) 2dd	Kanab	8/29/64	5290	Lamb Point Tongue	Many	Pond	100 gpm E		
42	Johnson	Frank Ghiglia	West side, Johnson Canyon	(C-43-5) 11aa	Kanab	8/29/64	5300		Several	Floods meadow	15-25 gpm E	59	
43	Johnson	Johnson house spring	End of rock nose west side, Johnson Canyon	(C-43-5) 12cba	Kanab	8/29/64	5320	Lamb Point Tongue	Several	Pipeline to house, plus ditch	5 gpm E	57	
44	Johnson		East side, Johnson Canyon	(C-43-4 1/2) 18ccc	Kanab	8/27/64	5150	Moenave? *			2-4 gpm E	60	May be rising on fault
45	Johnson Lakes	Johnson Lakes springs	East side and center, Johnson Lakes Canyon	(C-42-4 1/2) 32dab & dba	Kanab	8/28/64	5470	Lamb Point Tongue	Many	Dam, lake of 6-7 acres		62	C
46	Johnson Lakes	Pipe to lake	West side, Johnson Lakes Canyon	(C-42-4 1/2) 32dcb	Kanab	8/28/64	5450	Lamb Point Tongue	One	Pipe to lake	14 gpm M	58	C
47	Johnson Lakes	Flood Canyon	Base of cliff	(C-43-4 1/2) 5ddc	Kanab	8/27/64	5370	Top of Kayenta	Seeps		None - used by vegetation		
48	Johnson Lakes	Flood Canyon	Jct. of Flood & Johnson Lakes Canyon	(C-43-4 1/2) 8bb & 8ba	Kanab	8/27/64	5285	Alluvium *	Many		23 gpm M 8/27; 38 gpm M 8/28	59	C (sampled at 8 bbb) Source is probably lower part of Kayenta
49	Seeps Wash	Navajo Well spring	On gentle slope	(C-44-4) 32bcb	Kanab	8/26/64	5325	Shinarump Congl.	Seeps	Pipeline, concrete trough	None - used by vegetation		
DRAINAGE OF KAIBAB GULCH													
50	Deer Spring, Slide	Right pink, head of Slide Canyon	Under Pink Cliffs	(C-39-4 1/2) 16cd 1/		7/30/64	8500	Kaiparowits	Seeps in two alcoves	Pipeline, tank, troughs (abandoned)	1 pt/min M	62 *	100 yds from source
51	Deer Spring, Slide	East branch, head of Slide	West side of canyon	(C-39-4 1/2) 16dc 1/		8/21/64	8400	Kaiparowits		Pipeline to wooden tank (abandoned)	Dry		
52	Deer Spring, Slide		Bottom of gully	(C-39-4) 31dd 1/		8/19/64	6850		Seeps	Pond	2-3 gpm E		

No.	Sub-drainage	Owner, name of spring, or further information	Topography	Spring coordinate number 1/ = approx.	Nearby town or reference point	Date of record	Approximate altitude	Kind of rock	Openings	Improvements, accommodations, or use of water	Flow	Temperature °F	Remarks or other data
DRAINAGE OF KAIBAB GULCH - Continued													
53	Deer Spring, Slide		South side canyon, 75 ft up hillside	(C-40-4) 8cc 1/		8/19/64	6600	Cret ss	Many	Feeds meadow	2-3 gpm E	54	
54	Deer Spring, Meadow	Crawford Pass spring - north	Near head of canyon	(C-39-4) 7b-1 1/		8/22/64	8440	Cret ss	Seep	Runs into creek	1 qt/min E		
55	Deer Spring, Meadow	Crawford Pass spring - middle	Near head of canyon	(C-39-4) 7b-2 1/		8/22/64	8375	Cret ss	Seep	Runs into creek	9 qt/min M		C
56	Deer Spring, Meadow	Crawford Pass spring - south	Near head of canyon	(C-39-4) 7b-3 1/		8/22/64	8300	Cret ss	Seep	Runs into creek	1 gpm E		
57	Deer Spring, Meadow	Upper Meadow, north	SW side Meadow, 50 ft above floor	(C-39-4) 18b-1 1/		8/22/64	7700	Cret ss	One	Spring feeds a pond	3 gpm E		C
58	Deer Spring, Meadow	Upper Meadow, south	SW side Meadow, 50 ft above floor	(C-39-4) 18b-2 1/		8/22/64	7700	Cret ss	One	Spring feeds a pond	7 qt/min M		
59	Deer Spring, Meadow	Pipeline Canyon Spring	Under Pink Cliffs	(C-39-4) 16ac 1/		8/21/64	8400	Kaiparowits	Several	Pipeline, 4 troughs, pond	1-2 gpm E	47	C (48° where sampled)
60	Deer Spring, Meadow	Pipeline	Under Pink Cliffs	(C-39-4) 16db 1/		8/21/64	8400	Kaiparowits	Several	Feeds meadow	1-2 gpm E		
61	Deer Spring, Meadow	Meadow Canyon	Center and SE side Meadow Canyon	(C-39-4) 19a & 20b, c 1/		8/20/64		Cret ss	Many	Feeds meadow	100 gpm E	46-48	C
62	Deer Spring, Meadow	Crawford Canyon #1	Near head of Crawford	(C-39-4) 17bba		8/22/64	7675	Kaiparowits		Feeds meadow	20-25 gpm E		
63	Deer Spring, Meadow	Crawford Canyon #2	West side, Crawford Canyon	(C-39-4) 17bdb		8/22/64	7550	Kaiparowits	Seep		Damp only *		Vegetation suggests flow at some seasons
64	Deer Spring, Meadow		SW side, Meadow Canyon	(C-39-4) 33da 1/		8/20/64		Straight Cliffs over Tropic	Seeps		Seep *		Once site of homestead
65	Deer Spring, Meadow	Hiller	Near top of bench	(C-40-4) 9bb		8/22/64		Pediment gravel	Seeps	Pipeline, tank	1 gpm E *		Only a few drops/min actually collected
66	Deer Spring, Meadow	On Findlay Ranch	Bottom of arroyo	(C-40-4) 15dd 1/		7/31/64	6200	Alluvium	One	Flows into pond	1 qt/min E	60	
67	Park Wash, Riggs (Lower Podunk)	Riggs Spring	South side, Riggs Creek	(C-38-4) 33dd		8/20/64	7490	Cret ss		Collection box, plastic pipeline, 6 troughs	1 gpm M	45	C
68	Park Wash, Riggs		NE side, Riggs Creek	(C-39-4) 11bbc		8/19/64	7150	Straight Cliffs	Two		3-4 gpm E south, 6 1/2 gpm M north 5 gpm E	52	
69	Park Wash, Riggs		NE side, lower Podunk Valley	(C-39-4) 11ddc		8/20/64	6925	Straight Cliffs at top of Tropic	Two or more	Pond		49	C (north)
70	Park Wash, Riggs	Brown Ranch	NE side, lower Podunk Valley	(C-39-4) 13bbc		8/20/64	6900	Straight Cliffs at top of Tropic	Several	Pond	10 gpm E	52	C
71	Kitchen Corral		Base of mesa wall	(C-41-3) 27bac		8/26/64	5610	Chinle (Pet Forest Mem)	Seeps		1 pt/min E		
72	Kitchen Corral	Kitchen Corral spring	Head of small draw on K.C.Pt.	(C-41-3) 27bcd		8/26/64	5630	Chinle (Pet Forest Mem)	One	Pipeline & tank (abandoned)	1 qt/min E	57	
73	Kitchen Corral		End of Kitchen Corral Point	(C-41-3) 34cbb		8/26/64	5560	Chinle (Pet Forest Mem)	Seeps	Pipe, trough, pond	1 qt/min M	74 *	C; at discharge pipe
74	Kitchen Corral		Middle of Kitchen Corral Wash	(C-42-3) 3bcd		8/26/64	5475	Alluvium *		Pond		67	Water may be rising across bedrock dam

Table 2. — Records of selected springs in western Kane County, Utah . . . (continued)

No.	Sub-drainage	Owner, name of spring, or further information	Topography	Spring coordinate number <u>1</u> / <u>2</u> = approx.	Nearby town or reference point	Date of record	Approximate altitude	Kind of rock	Openings	Improvements, accommodations, or use of water	Flow	Temperature °F	Remarks or other data
DRAINAGE OF PARIA RIVER													
75	Bull Valley	Pine Spring	East side canyon, 40 ft up hill	(C-39-3) 10bb <u>1</u> / <u>2</u>		8/ 4/64		Ss over siltstone *		Collection box, pipeline, 3 troughs	1 qt/min M	58	C; Possibly in Winsor Fm
76	Sheep Creek, Willis Creek	Natural Bridge north	Below Pink Cliffs, alcove N of Natural Bridge		Bryce Canyon Natl. Park	8/ 3/64	8200	Kaiparowits	Two or more		$\frac{1}{2}$ pt/min E		
77	Sheep Creek, Willis Creek	Natural Bridge south	Below Pink Cliffs		Bryce Canyon Natl. Park	8/ 3/64	8200	Kaiparowits	Seep		Nearly dry *		Supports a few plants
78	Sheep Creek, Willis Creek	Headwaters, Willis Creek	South side, Willis Creek	(C-38-4) 11cdb	Cannonville	8/13/64	6825	Alluvium *	Many	None	50 gpm E	50-56	C; Possibly from Straight Cliffs or on Paunsaugunt fault
79	Sheep Creek, Willis Creek	About 100 yds south of ranch house	Center of valley, both sides Willis Creek	(C-38-4) 11dcd	Cannonville	8/ 3/64	6800	Alluvium *	Several	Flows to creek	$\frac{1}{2}$ gpm, north E; 5 gpm, south E	58	Possibly rises on Paunsaugunt fault
80	Sheep Creek, Willis Creek		Middle of broad alluvial valley, above present channel	(C-38-3) 16cc <u>1</u> / <u>2</u>	Cannonville	8/ 3/64		Alluvium *	Several	Ponds, ditch, sinks into alluvial bench	10 gpm M	58	C; probably from Jurassic rocks (Winsor?)
81	Cottonwood Hackberry	Side canyon west of Hackberry Creek		(C-40-1) 16cb <u>1</u> / <u>2</u>		7/21/64	5260	Navajo	Seeps for 500 ft or more		10 gpm E		
82	Cottonwood, Hackberry	Canyon west side of Hackberry Creek		(C-40-1) 21cc		7/21/64	5160	Navajo	Seeps along bedding plane		2 gpm E		
83	Cottonwood	Canyon west of Cot. Creek (Cottonwood #6)	Head of canyon	(C-40-1) 11 <u>1</u> / <u>2</u>		7/23/64		Navajo	Seeps in joints		8 gpm M	62	C
84	Cottonwood	West side main channel (Cottonwood #5)		(C-40-1) 14cd <u>1</u> / <u>2</u>		7/23/64	5150	Alluvium *	Seeps		5 gpm E	61	Probably from Navajo
85	Cottonwood	Mouth of canyon west of Cottonwood (Cottonwood #4)	Mouth of side canyon	(C-40-1) 14cb <u>1</u> / <u>2</u>		7/22/64	5200	Talus below Navajo	Two or more	Flows to creek	63 gpm M	60	C
86	Cottonwood	Cottonwood #3 (Byron Davies)	West side Cottonwood Creek	(C-40-1) 23ba, 14cd <u>1</u> / <u>2</u>		7/20/64	5160	Alluvium *	Many	Tank - then flows to creek	58 gpm M	60	C; may rise along fault in Navajo
87	Cottonwood	Cottonwood #2	Mouth of canyon west of Cottonwood Creek	(C-40-1) 23bc <u>1</u> / <u>2</u>		7/23/64	5120	Talus below Navajo	Seep		2 gpm E	65	
88	Cottonwood	Cottonwood #1	Mouth of canyon west of Cottonwood Creek	(C-40-1) 23da <u>1</u> / <u>2</u>		7/23/64*	5160	Joints in Navajo	One		1-2 gpm E		Recorded by J.C. Lawrence
89*	Henrieville Creek	Both sides U-54	Both sides of canyon	(C-37-1) 9bca, bbd	Henrieville, Garfield Co.	8/12/64	6600	Straight Cliffs Ss	Many	Flows into creek	200 gpm E	57	C; not shown on figure 2

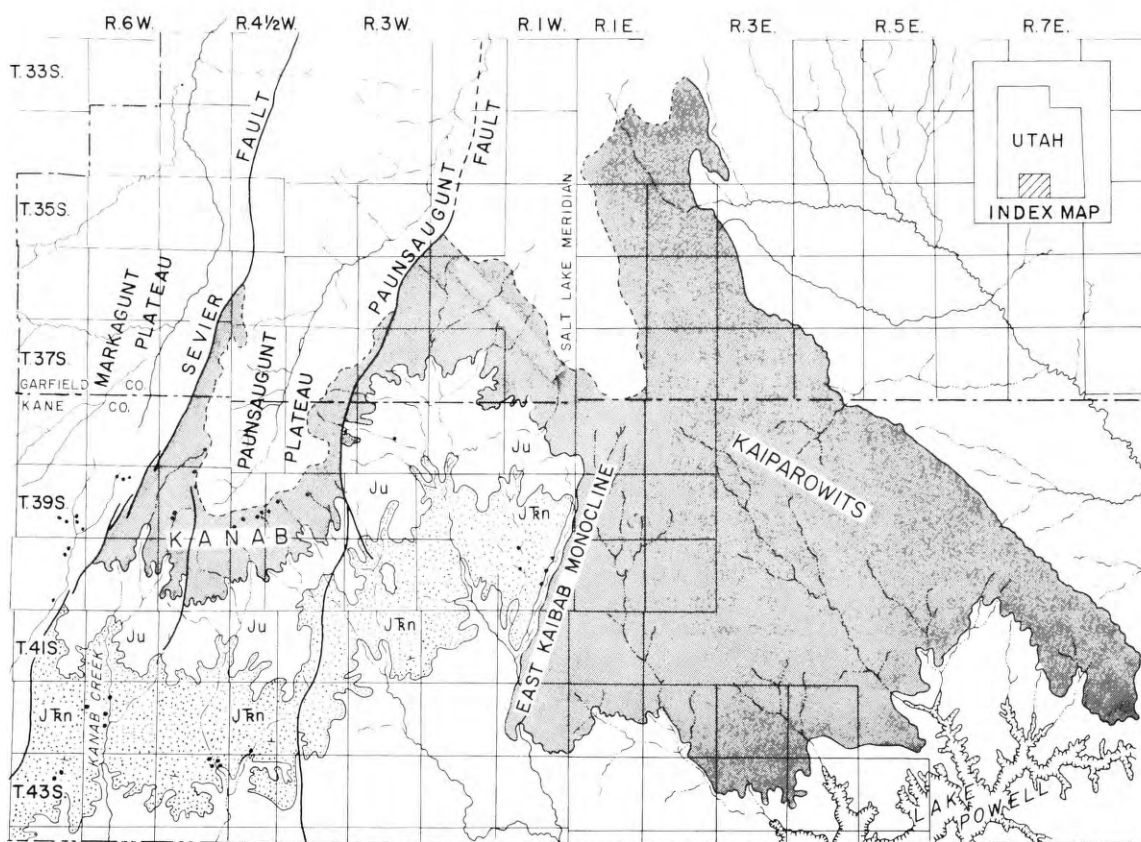


Figure 4. — Regional map of the Kanab and Kaiparowits coal fields showing areas underlain by coal (shaded), outcrop areas of Navajo Sandstone (J_N — stippled), outcrop areas of undivided Jurassic rocks (Ju), and selected springs in Kane County west of Salt Lake Meridian (black dots). Strike and dip symbols (X) indicate north-northeastward dipping structure between Sevier fault and East Kaibab monocline. Coal fields adapted from Robison (1964) and geology from Hintze (1963).

in Water-Resources Bulletin 5 (Goode, 1964); the only springs in this drainage included in this report are the two Yellowjacket springs in Yellowjacket Canyon and Harris Springs in Rock Canyon.

YELLOWJACKET AND HARRIS SPRINGS

The Yellowjacket springs (springs 1 and 2) yield less than a quart per minute each, and Harris Springs (spring 3) yields only about 3 gpm. Each of these springs yields water that is sufficient only to supply a few head of stock and to support a little local vegetation; none of these springs contributes to the flow of East Fork because their slight yields are dissipated long before reaching the river.

Drainage of Kanab Creek

Kanab Creek heads in a spring under the Pink Cliffs northeast of Alton. That spring and others in the drainage of upper Kanab Creek were discussed in Bulletin 5. Bulletin 5 also described how Kanab Creek is hydrologically divisible into upper and lower portions because the perennial flow of the upper portion does not reach the lower portion; instead, springs that rise in the lower portion sustain flow there (Goode, 1964, p. 35).

In the section that follows, Cottonwood Canyon, the main tributary of Kanab Creek west of Kanab, will be discussed first and then lower Kanab Creek. The creek that flows in Cottonwood Canyon joins Kanab Creek in Arizona, south of Fredonia.

COTTONWOOD CANYON AND TRIBUTARIES (WEST OF KANAB)

The creek in Cottonwood Canyon has perennial flow only in short reaches near its headwaters and in some tributaries. This flow is fed by springs issuing from the massive upper member and from the Lamb Point Tongue or lower member of the Navajo Sandstone and, like the flow of many streams in the area, fluctuates in response to daily evaporation and transpiration, and certainly also in response to local rainfall. (See also discussion of fluctuation in flow of the creek in Calf Pasture Hollow (Goode, 1964, p. 40) and of Hackberry Creek, p. 28 below). Flow beyond the mouth of Cottonwood Canyon probably occurs only during spring runoff or after intense storms.

The principal tributaries of Cottonwood Canyon are Water Canyon, South Fork, Indian Canyon, and Farm Canyon. During this study, springs were investigated in Water, Indian, and Farm Canyons, in upper Cottonwood Canyon, and in a small side canyon where Scotty Cor-

ral spring is situated. Springs in Water and Indian Canyons supply a pipeline (Plate 3-C) that contributes to the water supply of Fredonia, Arizona, about 7 miles southeast of the mouth of Cottonwood Canyon; the springs in Farm Canyon and in upper Cottonwood Canyon and the Scotty Corral spring are used locally to irrigate a few dozen acres of pasture, to support wet meadows, and/or to water stock.

The collection system for the Fredonia supply includes many small infiltration galleries that supply a few gallons a minute each and a couple of small dams that impound only a few thousand gallons of water each. Mr. Miles Farr of Fredonia reported that the system supplies about 6,000,000 gallons per month during the summer months. When I visited Indian and Water Canyons on August 5, 1964, I was unable to determine how much water was going into the pipeline, but the uncaptured yield from the springs in Water and Indian Canyon was supporting a flow of about 75 gpm from Indian Canyon at the junction of Indian and Cottonwood Canyons (fig. 2). This flow would be about half of the 140 gpm required to supply Fredonia with 6,000,000 gallons per month.

Springs in Farm Canyon and in upper Cottonwood Canyon in sections 3 and 10, T. 43 S., R. 7 W., (springs 4, 5, 6, 7, 8, and 9) issue from the basal part of the massive sandstone member of the Navajo. Springs in Water Canyon and in upper Cottonwood in section 15, and the Scotty Corral Spring (springs 10, 11, 12, and 13) issue from various horizons in the Lamb Point Tongue of the Navajo.

Waters from three of these springs (6, 8, and 11) were chemically analyzed. All have total solids of 220 ppm

or less, and the water from spring 8 in Farm Canyon, with a hardness of 78, was the softest water sampled and analyzed during the two years of investigations in Kane County.

LOWER KANAB CREEK

It was pointed out in Water-Resources Bulletin 5 (Goode, 1964, p. 35) that although upper Kanab Creek forms continuous drainage with lower Kanab Creek the two portions of the drainage system may be considered separate because "the sources of the base flow (ground-water runoff) for the two sections of the system are different, and normally only spring runoff and flood waters provide a continuous flow of water from the head of Kanab Creek through its lower reaches." (Views of Kanab Creek are on Plate 2 A and B.) Only two of the three headwaters springs (springs 14, 15, and 16) of lower Kanab Creek were reported in Bulletin 5, and their probable flow was estimated from the flow of Kanab Creek about 1-1/2 miles below the headwaters. Actually, the flow of lower Kanab Creek where it was estimated in 1963 near Big Lake is the result of contributions by many small seeps and springs, of which two others (springs 17 and 18), in addition to the three mentioned above, are recorded in this report. (It should be pointed out here that the flows of springs 14 and 16, which are herein indicated to have flows of about 25 and 15 gpm respectively, were reported in Bulletin 5 to have estimated yields of 300-400 and 200-300 gpm, respectively, because of the erroneous belief I then had that these were the only springs contributing to the flow of lower Kanab Creek.)

All these springs (14 to 18) and the many unreported seeps in this reach issue or appear to issue from the

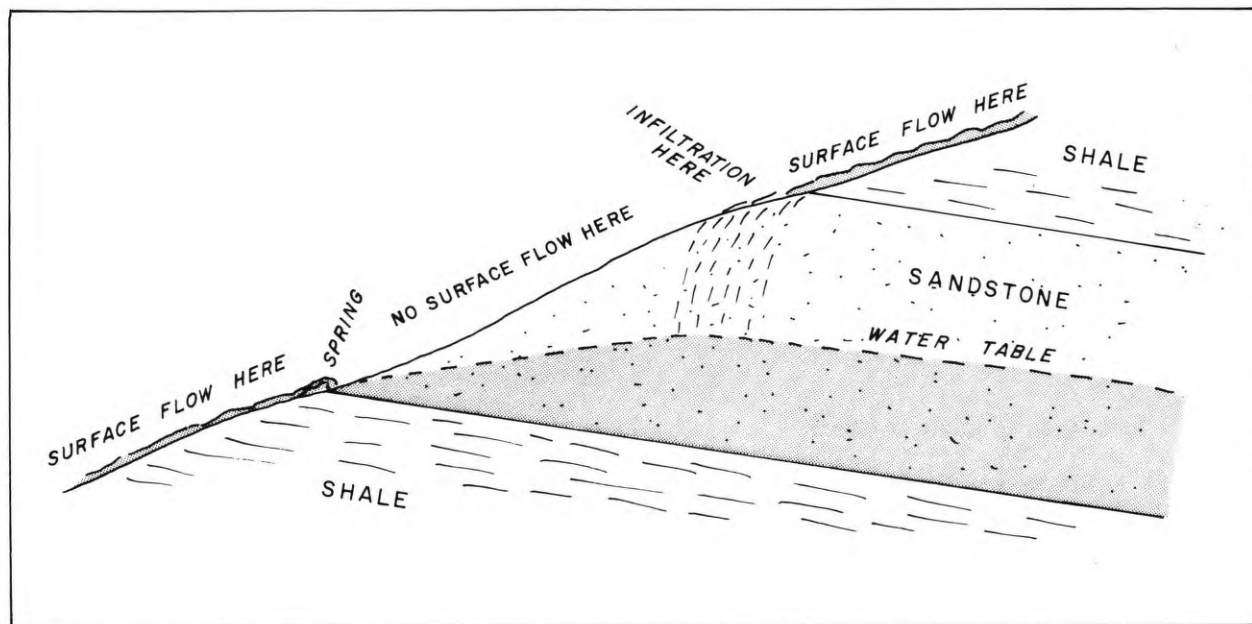


Figure 5. — Sketch to show how water flows over shale in stream channel, disappears as it flows over sandstone, and reappears downstream as a spring that issues from the top of a lower shale bed.

massive member of the Navajo, but two lines of evidence, a scarp and the quality of water, suggest that some of the water may be rising along a fault, probably one that has a throw of only a few feet but one that may be the control for the canyon of Kanab Creek in the reach below the headwaters spring. The upper headwaters spring (spring 14) issues from the base of a 10-foot-high bedrock scarp that trends nearly north-south across the channel of the creek, which here makes a sharp upstream turn to the west, across the scarp. The flow of this spring nowhere was large enough to permit me to collect an acceptable sample, but I did sample the water from spring 15 about 1000 feet downstream from the scarp. This water contained 508 ppm total solids and 142 ppm sulfates; both determinations for this sample were appreciably higher than similar determinations for waters from other springs in the Navajo (table 5), and they therefore suggest that the water has an anomalous source, perhaps along a fault.

Drainage of Johnson Canyon

Johnson Canyon and its tributaries, some of which reach to the Pink Cliffs at the south end of the Paunsaugunt Plateau, drain about 230 square miles above the mouth of Johnson Canyon (fig. 2). Yet this large drainage area yields only intermittent flow over most of the system and yields perennial flow only in short reaches that are supplied by springs. Like the drainage system of Kanab Creek, the drainage of Johnson Canyon can be considered a single system principally for the passage of flood waters and possibly for the passage of spring runoff; except for these unusual flows, the upper part of Johnson Canyon and its tributaries must be considered as hydrologically separate from lower Johnson Canyon.

The headwaters tributaries of Johnson Canyon, those to and above the junction with Cottonwood Canyon (east of Kanab) are, from west to east, upper Johnson, Thompson Wash, and Mill Creek and its tributary Tennys Meadow Canyon. Both Thompson Wash and Mill Creek join above Skutumpah Canyon and drain through it to Johnson Canyon. Although these headwaters tributaries are in the rainfall belt that receives probably more than 14 inches of precipitation each year (fig. 2), for much of each year the main channel of Johnson Canyon is dry where these upper drainages come together in sec. 24, T. 41 S., R. 5 W. Farther downstream, near Johnson, springs supply water for irrigation and maintain nearly perennial flow to the mouth of Johnson Canyon. Thus, the upper part of Johnson Canyon and its tributaries form one hydrologic unit and the lower part of Johnson Canyon and its tributaries form a separate hydrologic unit. The two form a single system for the passage of spring runoff and floods.

Springs in the main stem of Johnson Canyon and springs near the mouths of tributary canyons between Meadow Canyon and the vicinity of Johnson (fig. 2) yield more water than the combined yield of all springs in other tributaries and in other reaches of Johnson Canyon. Except for one possible spring (spring 44) that may rise

along a fault near the mouth of Johnson Canyon, all springs in lower Johnson Canyon issue from the Lamb Point Tongue of the Navajo.

Springs in Johnson Lakes Canyon, a tributary canyon near the mouth of Johnson Canyon, also issue principally from the Lamb Point Tongue, but these contribute no perennial flow that reaches the mouth of Johnson Lakes Canyon.

UPPER JOHNSON CANYON

Upper Johnson Canyon and its tributaries head in Jurassic and Cretaceous rocks in the sequence between the Carmel and the Straight Cliffs. Volcanic flows cover parts of the surface in the south-central part of T. 40 S., R. 5 W. No springs of any consequence issue from these rocks so the principal runoff is from the sporadic direct precipitation and local snowmelt.

THOMPSON WASH

A spring, (C-39-5) 26bad, that yields an estimated 4-5 gpm near the head of Thompson Wash was reported in Bulletin 5 (Goode, 1964, p. 34). Two other springs (springs 19 and 20) of similar low yield are recorded here. There probably are a few other low-yield springs in this drainage, but checks of the channel of Thompson Wash above Skutumpah showed no flow on July 28 or August 25, 1964, and examination of aerial photographs suggests there are no large spring areas above the mouth of Thompson Wash near Skutumpah.

SKUTUMPAH CANYON AND MILL CREEK AND TRIBUTARIES

Probably only floods and spring runoff normally provide flow through Skutumpah Canyon, but Mill Creek, the principal tributary, has perennial flow, above Skutumpah, in sufficient quantity, probably about 75 gpm, to supply an irrigation ditch. Most, if not all this flow is supplied by springs in the branches of Mill Creek -- informally called left fork and right fork -- above its confluence with Tennys Meadow. These springs not only provide a small amount of downstream flow but also supply fair amounts that are used by local vegetation. In addition, in the canyons of both Mill Creek and Tennys Meadow, especially right fork of Mill Creek and Mill Creek below the junction of right and left forks, there are small but dense stands of timber that probably receive their water supply from underground sources in the Kaiparowits and Wahweap formations, sources that are too deep to supply springs, or are insufficient to supply both springs and vegetation.

Mill Creek. Mill Creek's left fork has several spring areas, of which five (springs 21, 22, 23, 24, and 25, fig. 2 and table 2) are recorded here; but its right fork has no large spring areas, and only two tiny springs (springs 26 and 27), which flow about 1 pint per minute each, are recorded here. At the junction of right and left forks -- near spring 25 on figure 2 -- left fork yielded 125 to 150 gpm on July 28, 1964, whereas right fork had no flow.

The springs in the left fork of Mill Creek issue from the Kaiparowits below the Pink Cliffs (springs 21 and 22) in both west and east branches of left fork. Other springs issue from lower in the Kaiparowits or from the Wahweap at many places right to the mouth of left fork. The quality of the water from one spring below the Pink Cliffs (spring 22, table 5) is appreciably better than that from any other spring sampled from the Kaiparowits; this sample has only 214 ppm total solids and a hardness of 190. The quality of the water from the other spring sampled in left fork (spring 23, table 5) is at about the median of samples collected from the Wahweap; this sample has 356 ppm total solids and a hardness of 286.

Both springs (springs 26 and 27) in right fork of Mill Creek are near the divide to the northward-draining Paunsaugunt Plateau. One spring (spring 26) once fed a now abandoned pipeline about 2300 feet long. This spring is now covered and is evident only because water comes from the broken pipe about ten feet below the divide, which here is a saddle. It yields about 1 pint a minute. The other spring (spring 27) seeps out of Kaiparowits sandstone just below the Pink Cliffs in an alcove southwest of spring 26. It also yields about 1 pint per minute.

Tennys Meadow. Tennys Meadow is well watered by springs that probably rise from the Straight Cliffs Formation. All water from springs in the meadow was being consumed in the meadow on July 30, 1964; there was no downstream yield from the meadow. Spring 28 has at least two openings and yields about 30 gpm of water that contains 491 ppm total solids and has a hardness of 330 ppm (table 5). This water is of a quality better than median quality of water from other springs in the Straight Cliffs.

About half-a-mile downstream from the meadow a small spring (spring 29) waters a grassy spot on the west side of the canyon and provides about 5 gpm of downstream flow. On the east side of the canyon a smaller spring waters a grassy spot but provides no downstream flow.

LOWER JOHNSON CANYON

The presence of springs in lower Johnson Canyon was reported under the heading of "Johnson Wash" in Bulletin 5 (Goode, 1964, p. 41), and the total yield of the springs was estimated at 1 to 2 cfs, but no details of these springs were recorded. During this investigation, probably all springs within a mile of the road in Johnson Canyon were visited, and many of these are here recorded (springs 31 to 44 inclusive, fig. 2 and table 2). All but the last of these springs issue from the Lamb Point Tongue of the Navajo; possibly some issue from fractures or faults that parallel the trend of Johnson Canyon.

The springs in and near lower Johnson Canyon are in Meadow Canyon, Dairy Canyon, Rock Canyon, and Needle Rock Canyon as well as along the walls of Johnson Canyon. Although it was impossible to measure or even to make a close estimate of the yields of some of

these springs, their total yield may be about the 1 to 2 cfs estimated in Bulletin 5 because they provide water to irrigate croplands or to flood pastures of about 250 acres. By using the spring-flow factor of 3 acre-feet per acre per year that was used in Bulletin 5 (Goode, 1964, p. 5) and which is based on an estimate of the flow needed to keep meadows wet where the evapotranspiration rate is about 2 feet per year, the total yield of these springs must be about 750 acre-feet or a little more than 1 cfs. Since normally there is some downstream flow beyond the mouth of Johnson Canyon, the estimate of 1 to 2 cfs total flow for the springs seems reasonable.

Meadow Canyon. The many springs and seeps of Meadow Canyon, of which 4 are recorded here (springs 31, 32, 33, and 34), provide water for about 50 acres of wet meadow and for a pond filled with bullrushes, and supply water for the W. L. Johnson ranch house. The individual springs probably yield no more than 10 to 15 gpm each but their aggregate yield is probably more than 100 gpm because at least at times some outflow from the pond is available to irrigate land beyond the mouth of Meadow Canyon.

Samples of water from the meadow (spring 32) and from the Johnson house spring (spring 34) are similar chemically: both contain about 187 ppm total solids and have about 150 ppm hardness (table 5).

Dairy Canyon. The two springs recorded in Dairy Canyon (springs 35 and 36) are probably representative of the springs there, but many small seeps and the principal spring were covered by water, apparently flood water, retained behind a dam at the mouth of Dairy Canyon. Mr. Alvin Judd reported that the normal yield of the covered spring is "enough to fill a 4-inch pipe," or probably between 1/2 and 1 cfs. My estimate of the outflow from Dairy Canyon on August 29, 1964 was about 2 cfs, but this outflow included the release of some of the dammed flood water.

The chemical analysis of the sample collected from spring 36 shows appreciably higher total solids, 324 ppm, and much higher sulfate, 83 ppm, than is usual for samples from the Navajo, and I therefore believe that this water may be rising along a fault or fracture. The temperature of 56° does not indicate a deep-seated source for the water, but the high solids and sulfate suggest that the water may have come in contact with part of the underlying Kayenta, possibly along a fault.

Rock Canyon and east side of Johnson Canyon. The seeps in Rock Canyon (spring 37) on August 29, 1964 were supplying only enough water to wet about an acre of ground, and the reservoir formed by a low dam at the mouth of the canyon looked, from the condition of the headgate, as though it had not contained water or been used in several years.

Springs south of Rock Canyon (spring 38) issue from rock outcrops on the east side of Johnson Canyon, and, on August 29, 1964, yielded about 5 gpm flow in front

of the dam half-a-mile below Rock Canyon, and in addition maintained brim-full a pond of about 5 acres. Seepage from the pond provided a flow of about 2 gpm.

Unrecorded springs of probable low yield occur on the east side of Johnson Canyon near Johnson. These springs were observed only from a distance but are evidently issuing from near the base of the Lamb Point Tongue.

Needle Rock Canyon and west side of Johnson Canyon. Five springs (springs 39 to 43, inclusive) are herein recorded in Needle Rock Canyon and in other small canyons and embayments on the west side of Johnson Canyon.

Low dams at the mouths of Needle Rock Canyon and the next two unnamed canyons to the south are positioned to capture excess spring water and any possible flood waters. The dam in Needle Rock Canyon is appreciably below the springs in this canyon so I was able to examine these springs on August 29, but I could not see the springs feeding the other reservoirs because water behind the dams obscured spring orifices. The springs in all three of these canyons are recorded as spring areas (springs 39, 40, and 41), one for each canyon.

Small springs and seeps occur on both sides of Needle Rock Canyon; those on the north side have higher yields, although none was supplying water that reached the reservoir. Rather the water from these springs supported about 10 acres of damp and wet meadow above the reservoir.

The springs in the two canyons south of Needle Rock support ponds of about 5 acres each as well as a few acres of cattails beyond the ponds. The larger and more southerly pond (spring 41) had about a dozen ducks feeding on it when I was there.

Another spring (spring 42) on the west side of Johnson Canyon was yielding 15 to 25 gpm of water that was supporting a wet meadow of about 3 acres and supplying some outflow.

The last recorded spring (spring 43) on the west side of Johnson Canyon feeds about 5 gpm into an irrigation ditch and supplies about 1 quart a minute to a collection box that supplies a pipeline to the Johnson ranch house about 250 feet from the spring.

Spring? near mouth of Johnson Canyon. Spring 44 just north of the mouth of Johnson Lakes Canyon may issue from a fault or permeable bed in the Moenave Formation or it may be fed by underflow from irrigation farther up Johnson Canyon. It appears to issue from bedrock on what may be a fault scarp in bedrock. Its yield of 2 to 4 gpm adds little to the flow of Johnson Creek.

JOHNSON LAKES CANYON

Johnson Lakes Canyon is more clearly two distinct hydrologic units than either Kanab Creek or Johnson Canyon, for Johnson Lakes Canyon not only lacks perennial

flow throughout its length but also lacks through drainage for flood waters. Because alluvium from two side canyons in sec. 28, T. 42 S., R. 4½ W., has built a divide across Johnson Lakes Canyon there is no through passage for floods or snow-melt runoff. Runoff that reaches section 28 from the north and east does not pass the about 25-foot high divide but is trapped in a small depression in section 28. Thus this canyon, except for doubtful ground-water underflow beneath the divide, is separable into two completely distinct hydrologic units.

Upper Johnson Lakes Canyon. The presence of probably only a few feet of modern flood fill in the depression above the alluvium dam in section 28 suggests that there is little runoff from the drainage area of nearly 30 square miles in upper Johnson Lakes Canyon. This small amount of runoff could be due in part to the lack of water in that drainage, but the lack could hardly explain the absence of floods in an area that probably normally receives cloudburst-type rains of flooding proportions on essentially every drainage at least once a year. Rather the absence of runoff in this drainage is more likely due to the high porosity of the Navajo Sandstone which is exposed all over the drainage area or is covered by sandy detritus derived from the sandstone. Examination of the aerial photographs of the drainage of upper Johnson Lakes Canyon supports the idea of high porosity of this area because arroyos in the drainage pattern are discontinuous; many are only a few hundred yards long and very few are as much as half-a-mile long. Such discontinuous arroyos would develop on porous materials where fast seepage of flood waters would cause floods to rapidly lose their carrying and cutting capacities. Areas such as the drainage of upper Johnson Lakes Canyon would thus be good recharge areas for underlying aquifers even though they are in a belt of low rainfall.

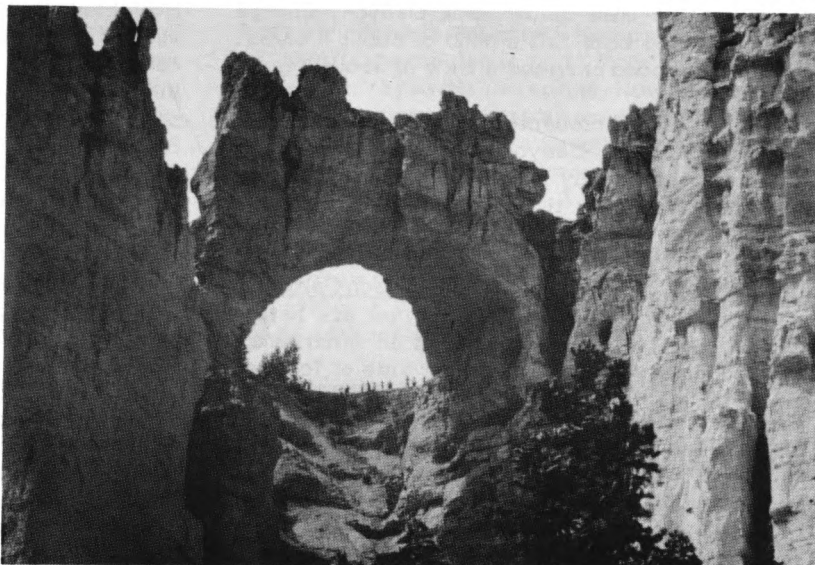
No known springs occur in upper Johnson Lakes Canyon; the scarcity of areas of concentrated vegetation suggests that little or no ground water comes to the surface.

Lower Johnson Lakes Canyon and Flood Canyon. In the vicinity of Johnson Lake (Plate 3-A and B) many springs and seeps, of which only springs 45 and 46 are recorded here, supply a reservoir (Johnson Lake) of about 7 acres, a wet meadow of about 10 acres, and, on August 27, 1964, maintained an outflow from the reservoir of about 50 gpm. This outflow disappeared into the alluvium of Johnson Lakes Canyon about half-a-mile below the reservoir. Another spring system, spring 48, at the junction of Johnson Lakes and Flood Canyons yields water that appears to be coming from sandstone in the Kayenta but which may in part be coming from the underflow down Johnson Lakes Canyon. The difference between the chemical constituents of the waters from springs 45 and 46 and the chemical constituents of the water from spring 48 (table 5) supports the idea the water from spring 48 is coming from the Kayenta.

Three measurements of the flow from spring 48 show fluctuations of yield that are due probably to daily fluctuations in rates of evapotranspiration, and also

PLATE 1

- A. Natural bridge in Bryce Canyon National Park. Bedding and columnar and cavernous weathering of Wasatch Formation clearly visible. (Text pages 27 and 30.)



- B. Town of Alton and Pink Cliffs in Wasatch Formation on Paunsaugunt Plateau. Bedded rocks below Pink Cliffs are Cretaceous sandstones and shales.



- C. Vermilion Cliffs (at the base), White Cliffs, and Pink Cliffs looking northward from Kaibab Plateau in Arizona. (Stratigraphy given in table 1.)

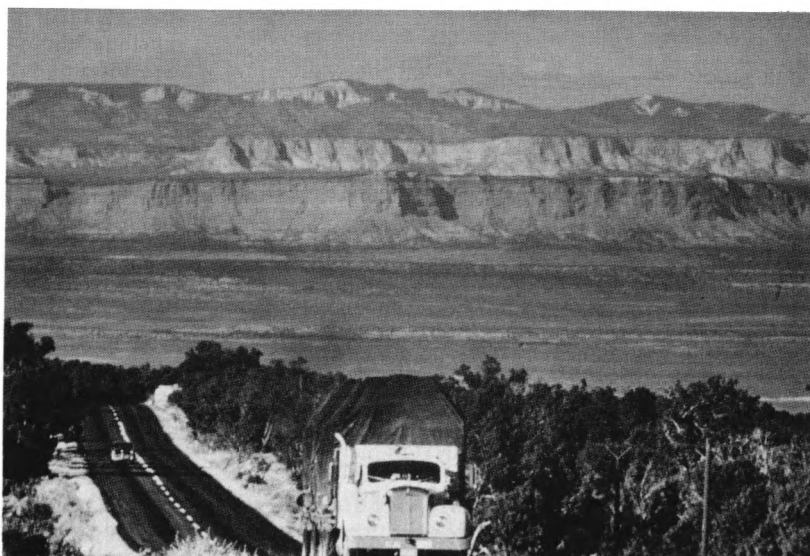
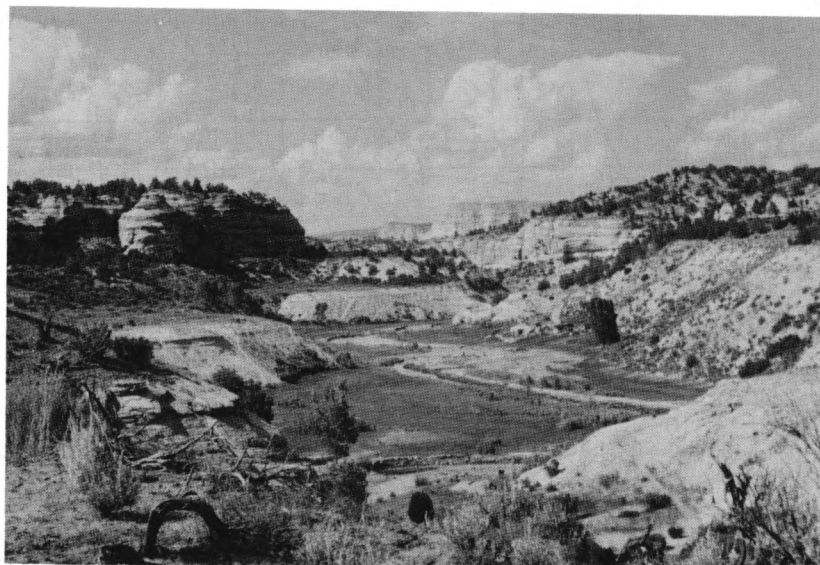
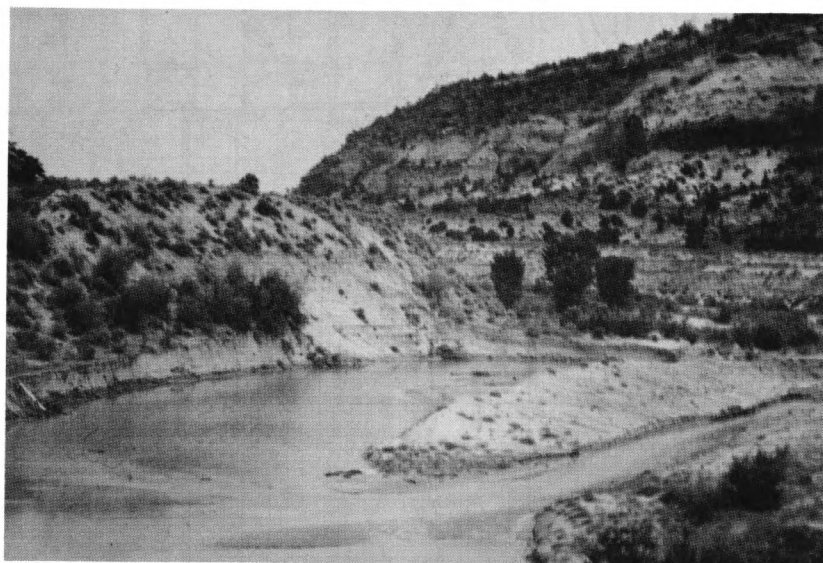


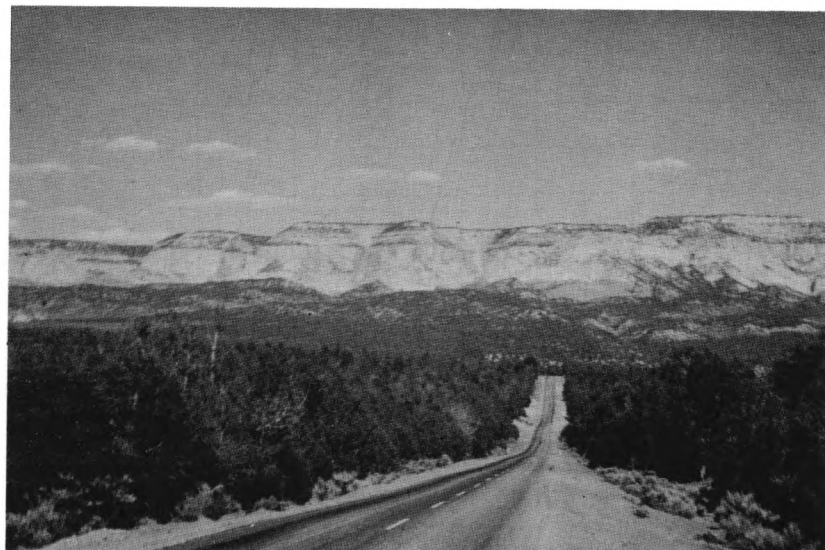
PLATE 2



A. Kanab Creek where it cuts into upper part of Lamb Point Tongue of Navajo Sandstone, upstream from B below. Upper massive member of Navajo forms cliffs in background.



B. Kanab Creek from bridge where US 89 crosses creek. (Text page 16.)



C. Elkheart Cliffs east of Mt. Carmel. This escarpment formed of upper massive member of Navajo Sandstone and overlying Carmel Formation is the upthrown block on east side of the Sevier Fault. (Text page 8.)

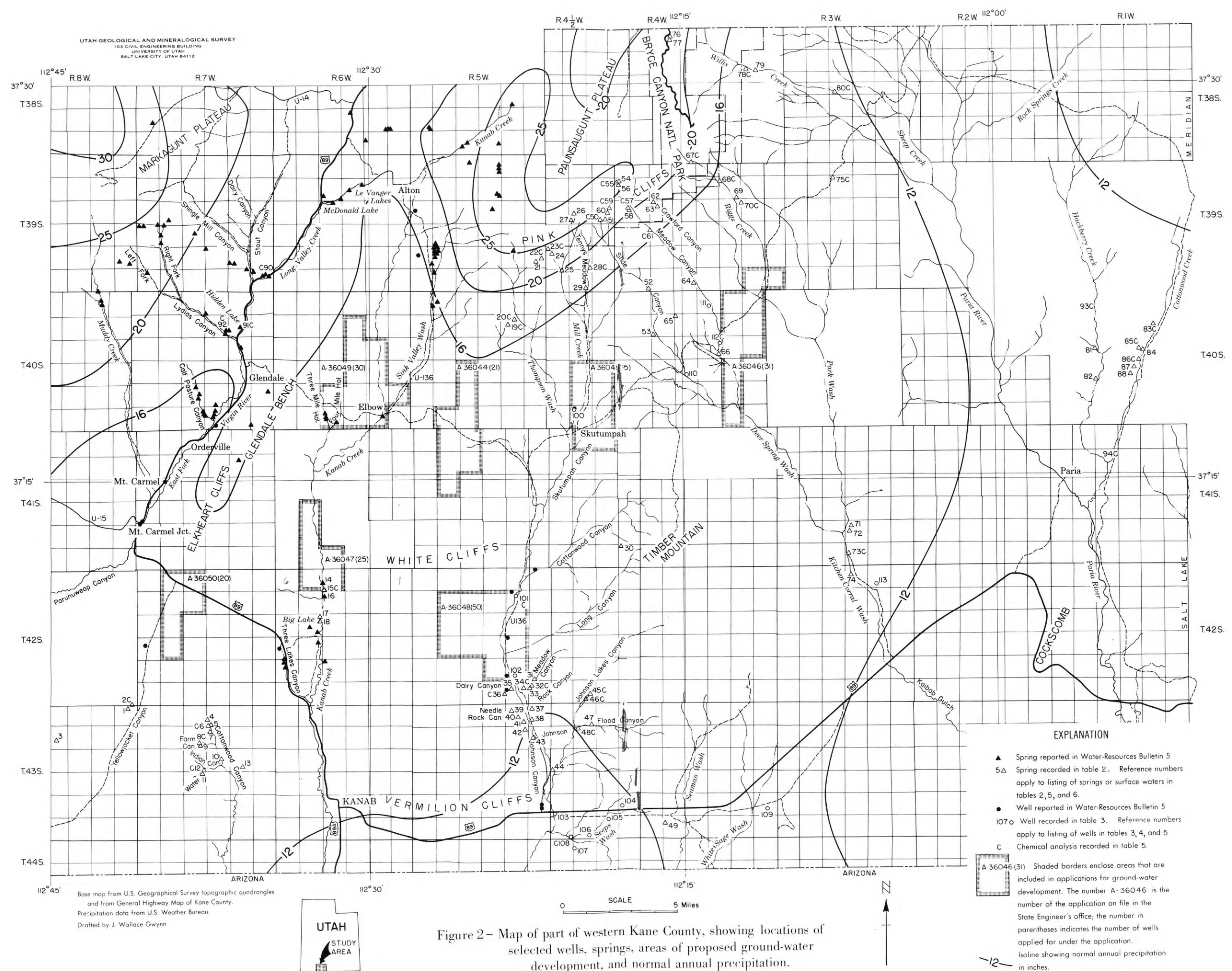
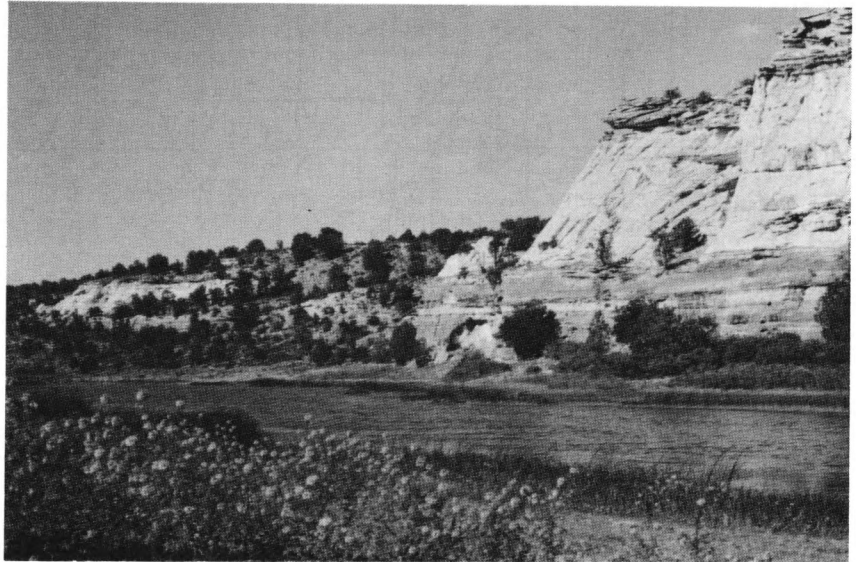
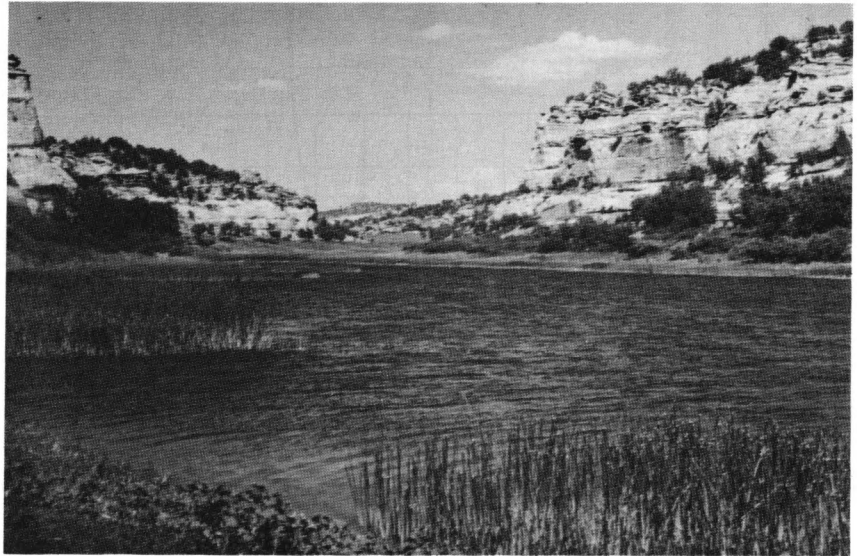


PLATE 3

- A. Johnson Lake (reservoir) in Johnson Lakes Canyon looking southwest. Lake is fed by springs coming from base of Lamb Point Tongue of Navajo Sandstone, which forms cliffs at far side of lake. (Text page 19.)



- B. Johnson Lake looking northeast.



- C. Pipeline carrying water to Fredonia, Arizona. View is in Water Canyon which cuts into Lamb Point Tongue of Navajo Sandstone. Darker tone below and parallel to pipeline on right is zone of seepage where water oozes from the rock up dip. (Text pages 16 and 31.)



PLATE 4



A. Subsiding flood in Rock Springs Creek, July 24, 1964. The low waterfall is held up by remnant of road washed out by this flood. (Text page 28.)



B. John Lawrence looking at same flood as pictured above. Dark line on opposite bank shows height of water at maximum stage of this flood. Picture taken about 2 miles downstream from A and about one hour earlier.

indicate that alluvium derived from the Kayenta is less permeable than alluvium derived from the Navajo. The flow of the stream in lower Johnson Lakes Canyon one mile below spring 48 was measured at 17 gpm at about 12:30 PM August 27, 1964. The flow at the downstream end of spring area 48, which consists of small springs and seeps for a distance of 600 to 700 feet into and beyond the mouth of Flood Canyon, was 23 to 24 gpm at 4:30 PM and 38 gpm at 8 AM on August 28. This evident fluctuation in downstream yield can probably be attributed to the daily evapotranspiration in the spring area: during the day the rate of evapotranspiration is high, so flow in the afternoon is low; during the night the rate is low, and early in the morning the yield is still high. The small downstream loss in flow shown by the difference between the 12:30 PM measurement a mile below spring 48 and an assumed yield at the spring area of something between 24 and 38 gpm shows that the influent seepage along the reach on alluvium from the Kayenta Formation is appreciably less than the seepage that causes a 50 gpm decrease in half-a-mile along a reach on alluvium from the Navajo (p. 21 above).

A traverse up Flood Canyon revealed no springs of any consequence, but I did record one seep (spring 47). Vegetation along the canyon walls suggests that most water that seeps into porous parts of the Kayenta eventually moves laterally toward canyon walls where it is used by plants.

SEEPS WASH

Seeps Wash nominally drains into Johnson Wash, but dams in sec. 31, T. 43 S., R. 4½ W., apparently capture all but exceptional floods, so that normally there is no outflow from the drainage of Seeps Wash. This area was visited in order to record some of the wells in the area (which are discussed in the section on wells). A feature called "Navajo Well" on Johnson quadrangle turned out to be a seep (spring 49) that once fed a stock trough but which now supports only a small patch of vegetation.

Drainage of Kaibab Gulch

Kaibab Gulch has two principal tributaries, Deer Spring Wash on the west and Park Wash on the east. Both these washes have tributaries that head below the Pink Cliffs at the south end of the Paunsaugunt Plateau. Kaibab Gulch was investigated along the reach called Kitchen Corral Wash about 8 miles north of US 89; but only some of the tributaries of Deer Spring Wash and Park Wash were investigated, the main stems of these washes were not traversed. The following discussion will treat first Slide Canyon, Meadow Canyon, and Crawford Canyon, all tributaries of Deer Spring Wash; second, Riggs Creek, a tributary of Park Wash; and third, the main stem of Kitchen Corral Wash.

SLIDE CANYON

Three branches of Slide Canyon head below or near the Pink Cliffs; these are informally designated here from west to east as left pink, right pink, and east branch. All three branches have good stands of ponderosa pines

which are probably subirrigated by ground water, but, except for a tiny flow in right pink, there was no sign of surface water in left or right pink on July 30, and none in east branch on August 21, 1964. Evidence of previous development of a spring (spring 50) in right pink, which yielded about 1 pint a minute on July 30, and of a dry seep (spring 51) in east branch, led to the recording here of these essentially insignificant springs.

Two other springs (springs 52 and 53) farther down Slide Canyon provide a little water for stock. Spring 52 yields 2 to 3 gpm and its water is captured in a small pond; spring 53 maintains about an acre of wet meadow on the southwest side of Slide Canyon about 75 feet above the canyon floor, and also yields about 2 to 3 gpm which has been used for stock watering in the canyon bottom.

MEADOW CANYON

Meadow Canyon is probably better watered than any other canyon that heads at the southeast edge of the Paunsaugunt Plateau. Small springs issue from the Kaiparowits Formation near the heads of canyons in Crawford Pass (springs 54, 55, and 56) and in Pipeline Canyon (springs 59 and 60), but this canyon also has good springs in the middle reaches, especially the spring area (spring 61) that waters the meadow for which the canyon is named. At least a dozen springs are scattered across the canyon bottom, which here is about 400 yards wide. Their flow is supplemented by seepage, especially near the southwest wall. Individual springs yield from 3 to 5 gpm each and their temperatures on August 20 ranged from 46° to 48°. Probably the water is coming from the Wahweap Formation. The analysis of the only sample collected shows that the water has total solids of 456 ppm and hardness of 309 ppm, both of which values are above the median for water from the Wahweap.

Two other spring areas were recorded in Meadow Canyon. Springs 57 and 58 are about 50 feet above the canyon floor and yield about 2 to 3 gpm each. They support tiny meadows and the yield of each is diverted into a pond on the canyon floor. Spring 64 is on the southwest side of the canyon about 1-1/2 miles below the meadow. Although only a seep now, this spring once supplied water for a homestead at the site.

CRAWFORD CANYON

Only the headwaters of the left fork of Crawford Canyon was visited during this investigation; the well-timbered branches of the right fork were not visited, but aerial photographs of the area were studied. These photos show no spring areas similar to the spring area in Meadow Canyon, but some of the stands of trees may be supported by underground sources that yield 10 to 15 gpm each. Examination of the photographs of the lower part of Crawford Canyon shows that it once had a system for diverting its flow and storing the water. According to Mr. Lynn Findlay the diverting ditch was built in 1925; presumably it was abandoned because it was difficult to maintain. The ditch picked up water from Crawford Canyon in the west-central portion of sec. 21, T. 39 S., R. 4

W., and transmitted it about 2 miles to natural depressions formed by landslides in sec. 34.

Left fork contains one principal spring area (spring 62) and a minor seep (spring 63) that was merely damp on August 22, 1964. The principal spring issued from near the top of the Kaiparowits and yields about 25 gpm which keeps wet an area of about 4 acres and provides downstream flow that sinks into the ground within a couple of hundred yards below the spring area.

An unusual feature in the upper part of left fork above spring 62 is a grove of bigtooth maples (Acer grandidentatum) covering about 3 acres. Trees of this kind are not common in the canyons of the area for these were the only ones I noted during the two field seasons I worked in the area.

RIGGS CREEK (LOWER PODUNK)

Riggs Creek has many small tributaries or branches that head in a huge crescent-shaped amphitheatre at the southeast edge of Bryce Canyon National Park. These tributaries provide no perennial flow through Riggs Creek, and the topographic map of the National Park shows only one spring, at Yovimpa Pass, between about 7500 feet and the rim, which here ranges from about 8300 feet to more than 9000 feet. However, the thick vegetation, especially the stands of ponderosa pine in the canyon bottom, suggests that fair quantities of water must be stored in the near-surface bedrock and in the surficial deposits even though this water doesn't come to the surface as springs. Four springs (springs 67 to 70) were recorded in Riggs Creek Canyon, the first probably from the Kaiparowits Formation and the others from the Straight Cliffs Formation. These springs yield from 1 to 10 gpm each and are now used principally for stock, although at one time spring 70 probably was the water supply for a ranch house.

KITCHEN CORRAL WASH

Kitchen Corral Wash is the main stem of Kaibab Gulch north of US 89. It has no perennial flow but provides a channel for flood waters that originate upstream or locally.

Four springs (springs 71 to 74) were recorded in this area and another unrecorded one is shown on the topographic map of the Buckskin Gulch quadrangle in sec. 23, T. 42 S., R. 3 W. Three of the recorded springs (71 to 73) issued from sandstone beds in the Petrified Forest Member of the Chinle Formation. Their yields were a quart or less per minute, and the springs therefore are probably useful only for stock. The fourth spring (74) appeared to be valley underflow that was forced to the surface by a bedrock dam created by a fault across the valley. Its yield is unknown but it was supporting a pond of about one acre.

Drainage of the Paria River

The Paria River and its many tributaries drain about 1,570 square miles between the Cockscomb and the Pink

Cliffs that flank the east side of Bryce Canyon National Park. In this investigation only about 100 square miles of the Paria drainage was covered. Traverses were made along Willis Creek, which heads below the Pink Cliffs at the east side of Bryce Canyon National Park, and along Hackberry and Cottonwood Creeks, which drain into the Paria about two miles below Paria. In addition, two other springs that nominally drain into the Paria (springs 75 and 89) were recorded, and two flash floods, one on Rock Springs Creek, which joins the Paria in T. 38 S., R. 2 W., and the other on Willis Creek, were witnessed and recorded.

WILLIS CREEK

Willis Creek has many tributaries and branches that reach up to the Pink Cliffs on the east side of the rim of Bryce Canyon, and, although these branches drain about 9 square miles above 7000 feet, they provided no surface flow in the creek at 7000 feet on August 3, 1964. At about 6825 feet the headwaters spring (spring 75) provided 50 gpm flow to the creek, and other downstream springs added to the flow so that the flow of the creek where it crosses the Skutumpah road about 6 miles below the headwaters spring was 40 gpm on August 4, despite losses due to evapotranspiration.

In an effort to get a sample of water from the Wasatch, I made two traverses in the alcove below Natural Bridge in Bryce Canyon National Park (Plate 1-A) to find a spring recorded by Marine (1963, p. 465) at the base of the Wasatch, but although I climbed about 200 feet above the base of the Wasatch, I was unable to find any trace of the spring. Below the base of the Wasatch I did find a seep (spring 77) in the Kaiparowits, but I doubt that this seep could have been the spring recorded by Marine. In the first alcove north of the Natural Bridge alcove I found a tiny spring (spring 76) that yielded about half-a-pint a minute from the Kaiparowits.

The headwaters spring of Willis Creek, mentioned above, and another spring (spring 79), about 500 yards downstream from the headwaters, probably both rise from the Straight Cliffs along the Paunsaugunt fault, in a manner similar to that diagrammed effectively by Marine (1963, p. 466) for the Merrill Ranch spring, which is on the Paunsaugunt fault about 8 miles northeast of the headwaters spring in Willis Creek.

About $3\frac{1}{2}$ miles east of the Paunsaugunt fault, spring 79 rises from alluvium of the floodplain above the channel of Willis Creek; probably its source is the underlying Winsor Formation.

HACKBERRY CREEK

Hackberry Creek probably has no perennial flow in its headwaters, and the perennial flow of the middle reaches does not go beyond the mouth of the creek during parts of the summer.

The headwaters of Hackberry Creek consist of three branches, here called west fork, middle fork, and east fork. East fork, which drains a much greater area than

the other branches, is about 10 miles long and has so deeply entrenched an impassable canyon in the Navajo Sandstone that west fork joins east fork over a waterfall (normally dry). The middle fork possibly traverses a reach of weakness in the Navajo and has been able to cut not only as deep a canyon as the east fork but also a broader one.

Traverses were made up Hackberry Creek from the mouth, down west fork from its head to the waterfall scarp, and down a small tributary of east fork from the Cottonwood-Cannonville road to a point where the channel dropped into an impassable box. No traverse was made down middle fork, but the upper part of its canyon was observed from the rim.

None of the headwaters branches of Hackberry Creek has springs, but somewhere in the middle reaches of the canyon is a spring or springs, probably in the Navajo, from which issues a flow of more than 1 cfs, which supplies the water that makes Hackberry Creek perennial in its middle reach. This spring, wherever it is, provides perennial flow through a reach of 7 or 8 miles, but the evapotranspiration in this reach in the summer causes the flow to be dissipated before it reaches the mouth. The daily fluctuations in the evapotranspiration rate also cause great daily changes in the flow of Hackberry Creek, as the following account illustrates.

On the July 21 traverse up Hackberry Creek I first saw water in the channel, in the form of a tiny front of a few gpm moving down channel, at about half-a-mile above the mouth. As I continued upstream I noticed that the flow was greater: about 4 miles upstream in mid-afternoon it was about 100 gpm. I continued the traverse and as I went upstream I recorded springs 82 and 81, which yielded only 2 and 10 gpm respectively, and gave little or no contribution to the creek. About 7 miles upstream the flow in the channel was 400 to 500 gpm, and later analysis of the creek water (sample 93, table 5) suggests that its source is the Navajo. I was already too late to continue the traverse upstream so I began the return to camp. After I had walked about 4 miles downstream I noticed that the stream flow appeared to be diminishing, and at about the contact of the Moenkopi and Kayenta*, or about $2\frac{1}{2}$ miles above the mouth, I saw that the flow stopped completely. From that point to at least the point where I had first seen water in the morning, the channel was wet but contained no moving and little standing water.

I made a check of the flow near the mouth on the following day and found that the water came down channel about 900 feet below where I had first seen it on the 21st, but there stopped completely. I then measured

*The canyon of the Hackberry Creek cuts across a small anticlinal structure in which Triassic rocks are exposed; both above and below the anticline the canyon cuts across the Navajo Sandstone.

a flow of about 50 gpm at the point where I had first seen it on the 21st. At the time of measurement water temperature was 96° , air temperature in the shade 99° , and sand temperature in the sun 130° . It would appear that the flow of 400 to 500 gpm at its origin, or about 2 acre-feet per day, literally dried up. Undoubtedly some flow was used by plants and some flow sank into the channel to provide a saturated base for the next day's flow -- but certainly a large part simply evaporated.

COTTONWOOD CREEK

Cottonwood Creek is dry in summer throughout most of its length, but in the middle reaches several springs that rise in or near the main channel or that rise in short side tributaries on the west side of the creek supply perennial flow for short distances. Five springs (springs 84 to 88) whose aggregate yield is 125 to 150 gpm were recorded near the channel or in tributaries in about a one-mile reach of Cottonwood Creek, about 6 miles above its confluence with the Paria River. All these springs probably originate from the Navajo, but the orifices of springs 84 and 86 are in alluvium so their ultimate source is not certain. One other spring (spring 83) which yields about 8 gpm, rises from the Navajo about half-a-mile west of Cottonwood Creek and about 2 miles north of the other springs.

It is not known for certain why the springs of Cottonwood Wash are concentrated in a short reach of Cottonwood Creek when similar rocks are exposed along the creek both north and south of the spring area. For most of its length of about 20 miles, Cottonwood Creek follows the folded contact between the Navajo on the west and overlying Jurassic rocks on the east. North of the five-spring area a fault that parallels the trend of Cottonwood Canyon is hidden by the alluvium in Cottonwood Creek (McIntosh, 1958, map). Possibly an extension of this fault cuts southward across the canyon of Cottonwood Creek and has broken the rock sufficiently for the water to escape from the Navajo. The tremendous recharge area where the Navajo is exposed between Hackberry and Cottonwood Creeks almost certainly assures that the Navajo is saturated at depth, and the springs here suggest that the Navajo is saturated above the level of the creek.

FLOODS ON ROCK SPRINGS CREEK AND ON WILLIS CREEK

Flood of July 24, 1964 on Rock Springs Creek. On July 24, 1964 John Lawrence and I made a traverse down west fork of Hackberry Creek and later were delayed from returning to our camp by a flood on Rock Springs Creek (Plate 4-A and B). While we waited for the flood to subside so that we could cross the creek we made a few estimates and crude measurements of flow.

In the southwest quarter of sec. 23, T. 38 S., R. 2 W. the channel of Rock Springs Creek is about 15 feet wide and about 8 feet deep (both dimensions estimated).

Rock Springs Creek and its tributaries drain about 50 square miles north of the Cottonwood Creek road to the headwaters on the southwest flank of Kaiparowits Peak in Garfield County (about 5 miles NNE from the northeast corner of figure 2). Kaiparowits Peak rises almost to 9200 feet, and much of the area is underlain by the Tropic Shale -- the high peak promotes thunderstorms and the shale permits high runoff, and the result is flash flooding.

When we arrived at the crossing at 3:10 P.M., the flood was already 3 feet below its crest (as indicated by the wet high-water mark on the banks) but still flowed about 3 feet deep (estimated). By 3:30 P.M. the water had dropped another 4 inches and we prepared to measure the flow by pacing off 100 feet along the bank. John stood downstream and I upstream at opposite ends of the 100-foot stretch. We then proceeded to time with a stopwatch the movement of floating objects between the points: I tossed into the water a large branch and started the watch, and John shouted as the branch passed him. The table shows measurements and approximate time at which some measurements were made.

Time	Elapsed time in seconds	Approximate speed of water in feet per second
3:45	13.6	8
	12.8	
	12.6	
3:50	12.8	
4:15	14.0	7
	15.0	
	15.8	
4:20	16.2	6
	17.2	

It can be seen that except for the first measurement, which was probably in error, the measurements fall into a reasonable progression although the fall-off of speed is greater in the last 5 minutes than in the previous 25. By 4:20 the water was probably between 1 and 2 feet deep and was slowing rapidly.

After this last measurement we stopped measuring in order to cross the creek before the subsiding waters completely silted the creek bottom.

Flood on Willis Creek. On the afternoon of August 13, 1964, shortly before 1 o'clock, a thunderstorm broke in the headwaters drainage of Willis Creek, and it became evident to me that a flood would come down the creek. I therefore stationed myself on the high pediment terrace above Willis Creek and waited. At 1:56 P.M. the flood arrived and I took a few pictures. Then I drove down the road to the next vantage point where the flood would pass. It arrived at 2:11 rumbling like a distant train and carrying shrubs, branches, and tree trunks in its forward wall. Later measurements on aerial photo-

graphs showed that it had traveled about 13,000 feet or $2\frac{1}{2}$ miles in 15 minutes between my two sightings at the different vantage points. The beginning of this flood, traveling at more than 14 feet per second, moved appreciably faster than the subsiding flood in Rock Springs Creek.

Ground Water

Summation of Storage and Recharge

The aquifers of western Kane County contain many million acre-feet of water. The principal aquifer, the Navajo Sandstone, probably contains nearly 20 million acre-feet, of which perhaps 10 million acre-feet should be available to wells that are drilled to the base of the Navajo. Recharge to the principal aquifer is probably in the range of 30,000 to 60,000 acre-feet a year, so withdrawals in excess of that amount will slowly deplete the aquifer. However, it may not be practical to withdraw more than 100,000 or 200,000 acre-feet of water a year and therefore the complete depletion of the supplies would require many decades.

Because there has been essentially no development of ground water in western Kane County, it must be admitted that the above statements are the result of interpretation of the geology of the area and of the springs and surface water. In the sections that follow I shall discuss that interpretation and justify the reasonableness of the figures for storage and recharge.

The Principal Aquifers

In western Kane County the principal supplies of ground water are in bedrock aquifers: in the Chinle, principally the Shinarump Member; in the two members of the Navajo Sandstone; in the sandstones in the Upper Cretaceous formations; and possibly but not probably in the Wasatch Formation. (See table 1 for a listing of stratigraphic units and their water-bearing properties.) Of these water-bearing units the most important is the Navajo Sandstone, which will be discussed in detail below; the other formations will be discussed briefly here. For the most part, the only available information about the aquifers comes from springs that issue from them so it will be necessary to repeat in part material already covered in Springs and Surface Water.

Locally, as at the mouth of Johnson Canyon (Frontispiece), the Chinle, probably the Shinarump Member, yields perhaps 300 to 500 gpm of water of fair-to-poor quality to individual wells. In a few places, as in Kitchen Corral Wash, the Chinle supports springs that yield a few gallons a minute.

The sandstones in the Straight Cliffs, Wahweap, and Kaiparowits formations yield water of fair quality to many springs that issue from cliffs below the Markagunt and Paunsaugunt Plateaus. The yields of these springs range from a few to several hundred gallons per minute; records of springs in these formations make up most of the entries in the spring tables in this re-

port and in Water-Resources Bulletin 5. The water-bearing sandstones in the Cretaceous formations are lenticular, however, and it is likely that only locally would they be able to supply more than moderate-to-small yields to wells.

The Wasatch Formation is principally a silty, fresh-water limestone that is probably cavernous (Plate 1-A). Likely it absorbs a large part of the precipitation that falls where the Wasatch is the cap rock on the Markagunt and Paunsaugunt Plateaus. But it is also likely that the water that gets into the Wasatch keeps on going, either through caverns that permit it to move down dip, or into the underlying formations, the Kaiparowits and Wahweap, which are porous enough in many places to absorb water from the Wasatch. Because the Wasatch is cavernous and is underlain by porous rocks that tend to drain the Wasatch, it is not likely that the Wasatch will yield water to wells except in a few localities.

Springs as Indicators of Saturated Aquifers

Springs that issue updip from some of the sandstones of Kane County have convinced me that many of these sandstones are saturated down dip and therefore contain large quantities of ground water waiting to be developed. Because no wells have penetrated these water-bearing beds where they are deep below the surface, my convictions have not been verified and it is therefore necessary for me to develop the reasoning that forms the basis for my convictions. First, I shall develop a little analogy using sand-filled barrels that stand out in the rain and then relate that analogy to the northward-dipping Navajo Sandstone (fig. 6).

The barrels pictured are uncovered and are filled with sand; they stand out in the open where rain can fall on them.

Obviously all the rain that does not evaporate will sink into the sand in the barrels; this is recharge. Barrel A has a hole in it, and it is clear that if that hole is capable of discharging as much water as is added to the

surface, the barrel will never fill up. If, on the other hand, the barrel has no leaks, as in B, the barrel will eventually fill up, and thereafter all rain that seeps into the surface of the sand will spill out over the low part of the lip; technically, this spillover is rejected recharge and may be likened to the water that comes out of some springs. The third barrel, C, more nearly represents the usual natural condition. This barrel has a hole that is not capable of carrying off all the rain that falls on the surface of the barrel, and, as a consequence, the water gradually rises above the hole and eventually will spill over the top. But the recharge to C through rainfall is not constant, whereas the leakage through the hole is nearly constant; hence, during some periods, when leakage is greater than recharge, the water level drops below the rim, and the overflow stops. Later, when recharge becomes appreciably greater, the water level rises and overflow occurs. Similarly, some spring areas respond to recharge. At some time after a period of recharge due to rain or snowmelt, springs will begin to discharge the overflow from the aquifers; the delay, or difference between time of recharge and time of overflow from the spring, is dependent to some degree on the distance from the recharge area to the spring, on the porosity and permeability of the rocks, and on how much below the "spillover" level the water level was when recharge began. All natural aquifers have leaks in them. These leaks may result in the movement of water completely away from the region of recharge, such as would occur in the barrel analogy if the barrel had a screen in its bottom; or they may simply result in very slow movement of water such as would occur if the less permeable materials above or below an aquifer were porous enough to allow a little seepage. Such an aquifer would become full if the recharge were greater than the seepage. And at least some of the time such an aquifer would reject recharge and spill out the excess in springs. But an aquifer that is overlain and underlain by less permeable materials, as shown in the illustration of figure 7, will not yield water to springs unless it is saturated to a level above the level of the springs. So long as the water table, the top of the zone of saturation, is below the outlet at the springs,

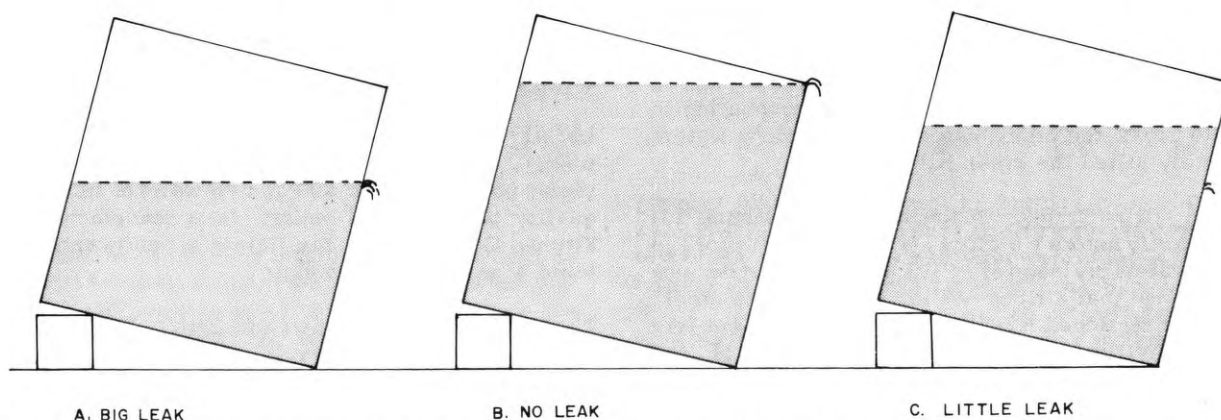


Figure 6. — Sketches to show effect of leaks on spillover of tilted barrels left out where rain can fall on them. A.—No spillover because big leak carries away all rainfall; B.—Spillover during every rain; C.—Spillover every time enough rain falls fast enough to raise water to lip.

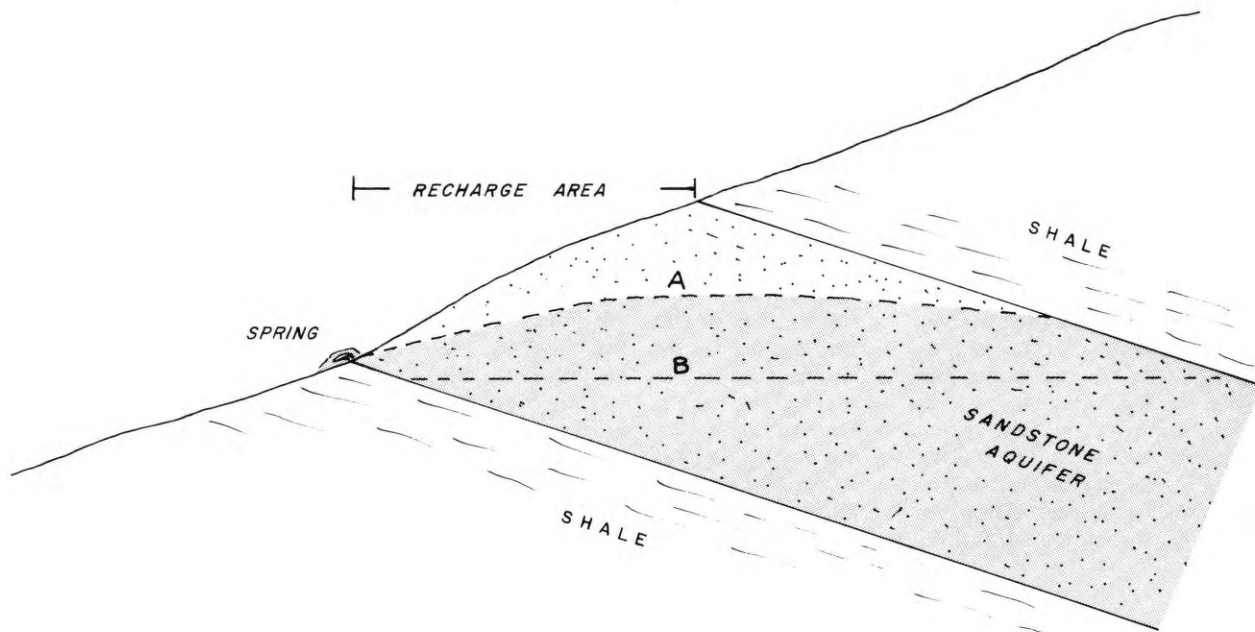


Figure 7. — Sketch to show relation of a spring to water table in a dipping aquifer. Some part of the water table must be above spring, as it is at A, if spring is to flow. Also, the aquifer must be saturated below water table or water would flow through aquifer down dip and not discharge at spring. If water table were at B, aquifer would be saturated below B but there would be no discharge at spring.

the aquifer will continue to absorb water which will move downward toward the water table, and the springs will remain dry. Therefore yielding springs in such an aquifer indicate that the aquifer is saturated down dip.

Storage in and Recharge to the Navajo Sandstone

The estimate of recoverable storage of 10 million acre-feet in the Navajo and the estimate of recharge of 30,000 to 60,000 acre-feet a year must be explained. Both estimates are speculative because data on which to base firm estimates are lacking. But even speculative estimates provide a basis for beginning development; and the data gathered during development can lead in the future to firmer estimates of storage and recharge. The bases for the estimates are discussed below.

STORAGE

The estimate of storage in the Navajo is based on the assumption that springs issuing up dip indicate an overflowing aquifer; the specific amount of 10 million acre-feet of recoverable storage is based on estimates of thickness of the zone of saturation, porosity, and areal extent of the aquifer.

Springs issue up dip from many aquifers in western Kane County; of these aquifers the Navajo Sandstone is the thickest and most continuous, so the springs that issue from the Navajo provide significant information about the aquifer that has the greatest potential for storage.

The regional dip of the Navajo ranges from 1° to 3° toward the north, or northeast, although broad folds of low amplitude in places modify the local dips toward the northwest or farther northeast. The upper part of the Navajo forms the high White Cliffs, and below them the more easily eroded lower part of the massive member of the Navajo forms a broad benchland, covered in part by sand dunes derived from the Navajo. Both the White Cliffs and the benchlands below them, like the other cliffs and terraces of the area, are dissected by southward-flowing streams that head in the Pink Cliffs. The canyons of these streams undoubtedly were developed in part along zones of weakness in the subjacent rocks; in the area where the streams cut the Navajo, the locations of some of these channels may have been determined by the low amplitude folds and the locations of others by faults. Probably some of the springs that issue from the Navajo, possibly some in Three Lakes Canyon, some in Kanab Creek, and some in Johnson Canyon, are controlled by faults; probably also some local springs are controlled by the dips of the low amplitude folds. But many of the springs, such as some in and near Cottonwood Canyon west of Kanab (Plate 3-C) and some in Johnson Canyon and in Johnson Lakes Canyon, rise up dip from the rocks, and they therefore indicate that the formation is saturated below the level of the springs. The interpreted relations are shown in figures 8 and 9. Figure 8 shows how dissection of a dipping aquifer by a canyon can partly drain an aquifer that dips opposite to the down gradient of the channel. Given sufficient water in the aquifer, springs can rise both from the bottom of the channel and from the walls of the canyon, as they do in Kanab Creek. Figure 9 shows how the zone of saturation in the Navajo thickens down

Estimates of Storage

dip so that in places it may be several hundred feet thick. Figure 9 also shows the relation of the recharge area to the saturated portion of the Navajo.

If the Navajo is saturated down the regional dip, as I have suggested here and as Gregory (1950, p. 198) believed, a vast amount of water is already in storage in that area. The amount in storage is dependent on the porosity of the rock, which Gregory (1950, p. 196) estimated to average 12 percent and to be as high as 20 percent in fracture zones; on the thickness of the saturated zones, say 250 feet; and on the areal extent of the part of the Navajo that can be penetrated by wells. In the part of Kane County from the Salt Lake Meridian westward to the Sevier fault the Navajo underlies about 1000 square miles. A simple calculation,

$0.12 \times 250 \times 1000 \times 640 = 19,200,000$
which shows:
porosity x thickness of zone of saturation
x square miles x acres in one square mile
= water in storage,

gives the amount of water in storage, or about 20 million acre-feet. If half of this can be recovered by wells less than 4000 feet deep*, there is an appreciable quantity of water waiting to be used. Obviously, these estimates would be lowered if the saturated zones are thinner than 250 feet or if the porosity is less than 12 percent; on the other hand, the saturated zones may aggregate more than 250 feet and the porosity in fractured areas, according to Gregory (1950, p. 196), is as much as 20 percent. In an earlier estimate (Goode, 1965) I used a sat-

*If the regional dip averages 3° , which seems to be a maximum rather than an average. Wells in T. 40 S. and northward may have to go more than 4000 feet to reach the base of the massive member of the Navajo. Wells in T. 41 S. and southward should reach the base of the massive member at depths of less than 4000 feet.

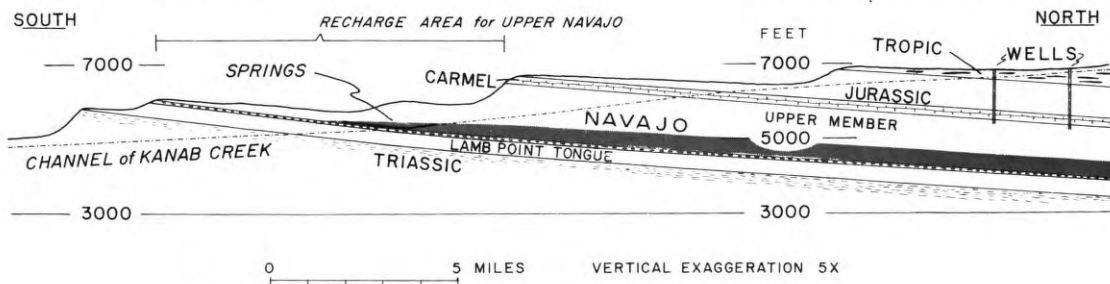


Figure 9. — Generalized geologic section approximately along Kanab Creek in Range 6 West. Shaded portion of Navajo represents presumed water body in upper massive member. Springs rise from bottom of Kanab Creek and also from walls of canyon as shown. Water body in Lamb Point Tongue not shown.

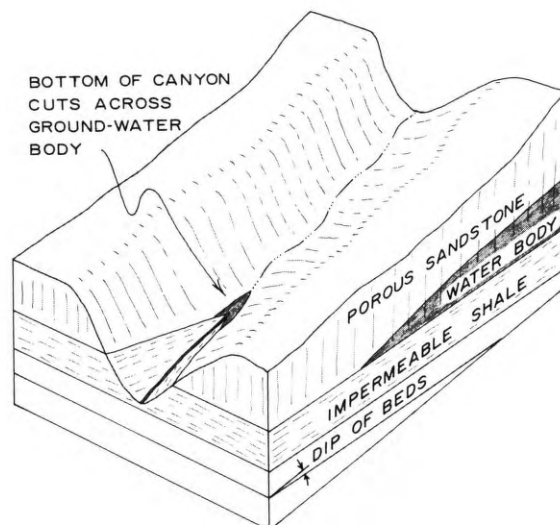


Figure 8. — Block diagram showing a canyon breaching a body of ground water. Spring area that rises out of rocks dipping up canyon must indicate a thickening water body down dip.

urated thickness of 200 feet and a porosity of 15 percent to arrive at the same figure for storage.

RECHARGE

Reliability of estimates of recharge

Recharge to ground-water reservoirs is dependent on so many difficult-to-measure factors that many estimates of the amount of precipitation that reaches the ground-water reservoir, although based on some valid measurements, are little better than guesses. Estimates of recharge are probably most accurate in developed areas that have little or no natural discharge of ground water and where the total amount removed from the reservoir is under man's control. If, in such an area, the long-term trends of water levels show stability, or little or no change in storage, then recharge must equal the amount removed by man. At the other end of reliability is the completely undeveloped area where few records of hydrologic data are available and where the extent and hydraulic characteristics of the aquifer must

**Factors
affecting
recharge**

be estimated from surface conditions. In such an area the simplest approach is to estimate recharge within broad limits after roughly considering the major factors involved. Such estimates are really considered guesses that can set the framework for reasonable development of the aquifers; the amount of development can then be modified up or down as actual data are gathered during development.

In order to better appreciate some of the problems of estimating recharge let us consider briefly some of the factors involved in recharge and some of the problems of measuring those factors. If we first recognize the problems of measuring the multiple factors involved in recharge, we may perhaps realize that an estimate within broad but reasonable limits will do as well as one based on valid but not all-inclusive measurements.

Natural recharge to the ground-water reservoir is dependent on such factors as amount of precipitation, seasonal distribution of precipitation, intensity of individual rain storms, permeability and slope of the ground surface, amount of soil moisture already in the ground above the water table, kind and density of vegetation, evaporation rate, relation of seasonal changes in evaporation rate to seasonal distribution of precipitation, and ratio of size of area having favorable recharge characteristics to size of area underlain by the ground-water reservoir.

Total-precipitation and seasonal-variation data are available for many areas, although normally not with the detailed coverage that would be most useful for recharge investigations. Storm-intensity data are being collected in some areas but normally would have to be estimated from short-term data. Slope and permeability of the land surface can be determined by detailed topographic mapping and an extensive coring program. Soil moisture in any soil of fixed physical properties varies with pattern and intensity of rainfall, and could be determined satisfactorily only by periodic measurements at rather frequent intervals. Kinds and density of vegetation can be plotted from field observations and aerial photographs. Evaporation rates from open water and from ground surfaces can be determined experimentally, but require an appreciable period of time. The last two factors, relation of seasonal changes in evaporation rate to seasonal distribution of rainfall and the ratio of recharge area to total area underlain by the aquifer, would be determined by an evaluation of the data collected for the other factors.

**Calculation
versus
a
considered
guess
of
recharge**

Obviously, the calculation of recharge for a large undeveloped ground-water reservoir by an evaluation of the factors mentioned above would be subject to many sources of error, so probably considered guesses within reasonable limits will do just as well as such calculations. For example, the recharge for a large reservoir that does not receive underflow from some adjacent or distant drainage has as its upper limit total precipitation and as its lower limit zero. The upper limit is certainly too high because some precipitation evaporates, some is used by plants, and some becomes runoff; the lower limit must be too low if any of the land surface is permeable and if precipitation at any time exceeds evaporation. We can therefore include the most obvious elements that must be considered and come up with an equation like this:

$$(1) \text{ Recharge} = \text{Precipitation} - \text{evapotranspiration} - \text{runoff}$$

In some parts of the area investigated, such as the upper part of Johnson Lakes Canyon, no runoff moves out of the drainage area. Thus for an area such as that the basic equation becomes:

$$(2) \text{ Recharge} = \text{Precipitation} - \text{evapotranspiration}.$$

Certainly the recharge in an area that has little runoff should be greater than in an equivalent area that has much runoff. That difference is measured by the difference in runoff.

If, for a moment, we consider the basic equation from the standpoint of runoff, we can write it thus:

$$(3) \text{ Runoff} = \text{Precipitation} - \text{evapotranspiration} - \text{recharge}.$$

We earlier considered that for some areas the runoff in equation (1) was zero and therefore only the factors of equation (2) are significant. Similarly, we can find some areas where the materials are so impermeable that no recharge occurs, or where the reservoir is already full and all recharge is rejected, or where the amount that goes into recharge at some high place in the system is matched by an equal amount of discharge that shows up in runoff. Of these three hypothetical situations, the last is most likely an approximation of the conditions in the bedrock aquifers in western Kane County. Unless these aquifers are acting as northward-draining conduits that transport water to some un-

**Measurement
of
factors
that
affect
recharge**

Table 3. — Records of selected wells in western Kane County, Utah.

These records came from the Office of the State Engineer or were supplied by the well owners. They supplement the records of wells published in Table 4, Water-Resources Bull. 5. Together, the two tables record most wells in Kane County.

Reference number: number used to identify well on figure 2 and

in other tables. Coordinate number: system is illustrated in figure 3 and is described in text. Use of water: Irrig = irrigation; dom = domestic. Other data available: C = chemical analysis in table 5; L = Driller's log in table 4. An asterisk (*) in any column indicates further information in Remarks.

Reference Number	Well coordinate number	Owner or user	Year drilled	Depth of well (feet reported)	Diameter of well (inches)	Reported yield (gpm)	Use of water	Water Levels		Other data available	Water-bearing formation	Remarks
								Altitude of land surface datum ± = approx.	In feet above (+) or below (-) land surface			
DRAINAGE OF JOHNSON CREEK												
100	(C-40-4½)32bab2	Graydon Robinson	1963	135	16	MILL CREEK			-35?	L		
101	(C-42-5)11bda	R.S. Bunting	1963	245	16	600 E	Irrig	5540	-84	C, L	Navajo Ss	
102	(C-42-5)26cda	Lamar Johnson	1960	380	10	800	Irrig	5430 ±	-8	L	Navajo Ss	
103	(C-43-4½)30cca	L.F. Little	1955	347	10			5120 ±	-57½	L		
104	(C-43-4½)27cba	Consumer's Agency	1959	240	10	50		5250 ±	-65	L		
105	(C-43-4½)33abb	R.A. Von Hake	1956	94	16	316		5220 ±	-24	L		
106	(C-43-4½)32ddb?				16			5150	-5½ *		Chinle?	Measured 8/24/64
107	(C-44-4½)5bcc	R.A. Von Hake			16	*	None		0			Flowed a trickle 8/26/64
108	(C-43-4½)31ddd	H.B. Hamblin			8	300-350	Irrig	5110 ±	+80	C, L	Chinle?	
109	(C-43-4)25dc	Utah Emergency Relief	1935	622		WHITE SAGE WASH		5400 ±	1	L		
DRAINAGE OF KAIBAB GULCH												
110	(C-40-4)21cad	Lynn Findlay	1935	90	6	50	Stock		-30		Alluvium	
111	(C-40-4)3dcb	Lynn Findlay	1935	140	8	30-40	Stock		-25 -30		Alluvium	
112	(C-40-4)15add	Lynn Findlay ranch well	1935	147	6	20	Dom		-25 -30	C	Alluvium	
113	(C-42-3)2cda	King Manganese Corp.	1952	300	6	1	Mining	5720	65	L		

known points of discharge to the north -- which seems most unlikely because the land lies at consistently high elevations north of the southward-draining streams of Kane County -- the bedrock aquifers probably are not transmitting water northward but instead probably are discharging from springs about as much water as they receive as recharge.

From the above we can make some generalizations. For any two areas where the precipitation and evapotranspiration are respectively equivalent, recharge and runoff will bear an inverse but complementary relationship to each other so that the sum of the two will be nearly a constant -- call it K.

$K = \text{Recharge} + \text{runoff}$
As recharge approaches 0,
 $K = \text{runoff};$
and as runoff approaches 0,
 $K = \text{recharge}$

The records of runoff of the streams of western Kane County are not only meagre but it has been recognized that some part -- quantity unknown -- of the runoff of many southward-flowing streams is the result of transdivide migration of ground water from the drainage of the northward-flowing Sevier River (Goode, 1964, p. 41-43). Nevertheless, it should be possible to put limits on runoff plus recharge and then put limits on recharge. For the United States as a whole (where recharge and discharge of ground-water aquifers are assumed to be equal), runoff is 30 percent of precipitation (Leopold and Langbein, 1960, p. 31). In many semi-arid regions where the major amounts of precipitation fall during the winter or during the time of low evaporation, the evapotranspiration is assumed to be about 75 percent, thus leaving 25 percent for runoff and recharge. Suppose, therefore, we say that for most of western Kane County the recharge and runoff should be between 10 percent and 20 percent of total precipitation. For areas underlain mostly by the relatively impermeable Tropic Shale recharge would be low and runoff high, but for areas underlain by the porous Navajo Sandstone the recharge rate should be high and runoff low. In areas underlain by Navajo the recharge may approach the maximum of 20 percent of total precipitation.

In Kane County the outcrops of Navajo between the Salt Lake Meridian and the Sevier fault cover an area of about 400 square miles. Rainfall is between 12 and 16 inches and may average 14 inches (fig. 2). Twenty percent of 14 inches would be 2.8 inches, and

Estimate of recharge

the total recharge would be 2.8×400 square-mile-inches of water, and be equivalent to

$2.8 \times 400 \times 640 \div 12$ or
59,700 acre-feet for the 400-square-mile area, or
 $2.8 \times 640 \div 12 =$ about 150 acre-feet per square mile

If we want to be conservative we can reduce the infiltration to 10 percent of the precipitation; in that case the recharge over the 400-square-mile area of Navajo outcrop would be about 30,000 acre-feet a year.

Wells

Records of 17 wells in western Kane County were reported in Water-Resources Bulletin 5, and I stated that probably fewer than 25 wells existed in western Kane County (Goode, 1964, p. 44). In this report records of 14 additional wells are given in table 3, and I now realize that even these records do not complete the listing of all water wells in Kane County west of the Salt Lake Meridian. Likely there are 10 to 15 unreported wells, or a total of perhaps 40 or 45 wells.

Drillers' logs of 9 of the 14 wells of table 3 are given in table 4. These logs can be useful to future water users who plan to develop wells in the same general areas as the existing wells; to some degree they can help in predicting materials to be encountered and depths to water-bearing strata.

Proposed Withdrawals and Their Effects

Proposed withdrawals

In the July 9, 16, and 23, 1964 editions of the Southern Utah News, the weekly newspaper published in Kanab, the Utah State Engineer published a notice to water users to the effect that Utah Construction and Mining Co. of San Francisco, Calif., had filed seven applications to withdraw a total of 110 cfs of water (equivalent to nearly 80,000 acre-feet per year) from about 192 20-inch wells in 66 sections in Ts. 40 to 42 S., Rs. 4 to 7 W. (See fig. 2.) This water would be totally consumed by a coal-fired steam-electrical generating plant to produce 2 million kilowatts of power. The plant would be located near the Elbow (in sec. 35, T. 40 S., R. 6 W. on fig. 2) and the power would be transmitted to southern California.

The published notice did not disclose the proposed depths of the wells, but presumably all wells were intended to withdraw water from the Navajo Sandstone, from either the upper massive member or the underlying Lamb Point Tongue. The intended pumping rate

Table 4. — Drillers' logs of selected wells in western Kane County, Utah, grouped by drainage area as in table 3.

These records supplement similar records that were published in Water-Resources Bulletin 5. Geologic interpretations that appear in parentheses are by the author. The first number given for each well is the reference number by which the well can be located on

the map of figure 2. The second number is the standard coordinate number illustrated in figure 3 and explained in the accompanying text. Altitudes are of land surface at well in feet above sea level; * indicates perforated interval; ± indicates approximate.

Drainage of Johnson Canyon

100, (C-40-4½)32bab-2. Kane County, Mill Creek, north of Skutumpah. Graydon Robinson, owner. Altitude, 6000 ±; depth, 135 ft; diameter, 16 inches to 110 ft.

	Depth, feet
Soil	0 - 5
Dry gravel	5 - 30
Dry gravel	30 - 35*
Gravel, wet	35 - 45*
Silt and sand	45 - 55*
Gravel	55 - 66*
Clay	66 - 72*
Gravel	72 - 80*
Clay and sand	80 - 83*
Red clay	83 - 90*
Clay and sand	90 - 125
Red sticky clay	125 - 131
Clay and sand	131 - 135

101, (C-42-5)11bda. Kane County, about 9 miles north of mouth of Johnson Canyon. R. S. Bunting, owner. Altitude, 5535 ±; depth, 245 ft; diameter 16 inches to 116 ft, 8 inches 116 - 245 ft.

	Depth, feet
Clay	0 - 30
Sand	30 - 50
Clay and sand	50 - 92
Gravel, pea gravel with water	92 - 93
Hard pan	93 - 98
Red sandstone, bedrock (Navajo Sandstone, upper member)	98 - 100 100 - 110* 110 - 200
Red sticky shale (Kayenta, Tenney Canyon Tongue)	200 - 236
White sandstone (Navajo, Lamb Point Tongue)	236 - 245

102, (C-42-5)26cda. Kane County, about 5 miles north of the mouth of Johnson Canyon. Lamar Johnson, owner. Altitude, 5430 ±; depth, 380 ft; diameter 10 inches to 185 ft.

	Depth, feet
Navajo Sandstone (Upper member)	0 - 165 165 - 181*
Wingate Sandstone (Navajo, Lamb Point Tongue)	181 - 185* 185 - 380

103, (C-43-4½)30cca-1. Kane County, near US 89 and Johnson Wash. L.F. Little, owner. Altitude, 5120 ±; depth, 347 ft; diameter 10 inches to 130 ft, 8 inches 130 to 331 ft.

	Depth, feet
Sand and soil	0 - 2
Sandy clay and rock	2 - 10
Brown clay	10 - 22
Muddy sandstone, water at 32 ft	22 - 32(?)

Drainage of Johnson Canyon (continued)

103, (C-43-4½)30cca-1 cont.

Brown clay, water at 55 ft	35(?) -	55
Quick sand	55 -	80
Muddy sand	80 -	95
Clay and gravel	95 -	99
Coarse gravel	99 -	101
Sticky clay	101 -	103
Gravel and clay	103 -	128
Sandy clay	128 -	130
Blue clay	130 -	290
Gray clay	290 -	305
Brown clay	305 -	318
Blue sandy clay	318 -	330
Sand, salty water at 330	330 -	341
Blue clay	341 -	344
Brown clay	344 -	347

104, (C-43-4½)27cba. Kane County, near US 89 and Seeps Wash. Consumers Agency, Inc., owner. Altitude, 5250 ±; depth, 240 ft; diameter 10 inches to 87 ft.

	Depth, feet	
Fine red sand and clay	0	- 40
Sticky red clay	40	- 53
Clay, some bentonite	53	- 60
Fine sand and clay, water at 71 ft	60	- 72
Fine sand	72	- 76
Pea gravel and sand, cemented	76	- 89
Clay and decayed wood	89	- 91
Fine sand and light clay	91	- 98
Sand and gravel, cemented	98	- 162
Broken layers of sandstone, loose	162	- 168
Very sticky red clay, small gravels and sand	168	- 175
Sandstone chunks, sand and gravel, red clay	175	- 192
Coarse sand and gravel, small cobbles, red clay base	192	- 203
Sticky red clay (dry)	203	- 209
Brown formation, very firm clay (dry)	209	- 217
Brown clay formation (dry)	217	- 240
Water samples taken from 80, 150, 175, and 200 ft.		

105, (C-43-4½)33abb-1. Kane County, near Seeps Wash. R.A. Von Hake, owner. Altitude, 5220 ±; depth, 94 ft; diameter, 16 inches to 22 ft.

	Depth, feet
Sandy clay	0 - 10
White clay	10 - 16
White sand	16 - 19
Yellow sand	19 - 31
Sandy clay	31 - 40
White sand and gravel	40 - 79
Gray sandy clay	79 - 82

Drainage of Johnson Canyon (continued)

105, (C-43-4½)33abb-1 cont.

Red shale	82 -	92
Red sand shale	92 -	94
Water-bearing strata 28 to 79 ft		

108, (C-43-4½)31ddd. Kane County, near Seeps Wash. H. B. Hamblin, owner. Altitude, 5110 ±; depth, 269 ft; diameter, 8 inches.

	Depth, feet
Red clay	0 - 14
Gray clay	14 - 17
Red clay	17 - 37
Sand and gravel	37 - 39
Red clay	39 - 66
Red sandy clay	66 - 72
Red and gray clay	72 - 92
Red clay	92 - 107
Gray and blue clay	107 - 126
Red clay	126 - 150
Red and gray sandy clay	150 - 203
Gray sandy clay, "hard"	203 - 217
Hard gray sand	217 - 235
Gray sand and gravel	235 - 255
Gray sandy shale, "hard"	255 - 268
Red sandy shale, "hard"	268 - 269
(Probably all Chinle Formation)	

109, (C-43-4)25dc. Kane County, near White Sage Wash. Utah Emergency Relief well. Altitude, 5400 ±; depth, 622 ft; diameter 10(?) inches.

	Depth, feet
Red clay	0 - 120
	120 - 200
Broken shale	200 - 210
Quartz conglomerate	210 - 300
Hard quartz	300 - 360
Gray lime	360 - 400
Lime and quartzite	400 - 500
Blue lime	500 - 600
Black and blue lime	600 - 612
Blue shale	612 - 622

Drainage of Kaibab Gulch

113, (C-42-3)2dda-1. Kane County, about 4 miles north of US 89, near Kitchen Corral Wash. King Manganese Corp., owner. Altitude, 5720 ±; depth, 300 ft; diameter, 6 inches to 65 ft.

	Depth, feet
Sandy loam	0 - 15
Sandy clay	15 - 65
Sand and little water	65 - 67
Shale	67 - 300

was indicated at 2 cfs for each well, but the large number of wells suggests that only 25 to 30 percent of the wells would be pumping at the indicated capacity at any one time. The placing of the wells in 66 sections which are scattered over about 300 square miles suggests that a large area of the aquifer will be exploited at once so that the aquifer will not become depleted anywhere. The planned withdrawal of 110 cfs from 66 sections would remove an average of less than 1.7 cfs from each section or a little more than 1200 acre-feet a year from each section.

The question of concern to the appropriator who plans the development of the aquifer is, Will I be able to remove this water at the planned rate over a long period of time?; and the question of concern to water users in the area is, What effect will this development have on my water rights?

The answers to these questions cannot be learned until some wells are drilled and tests are made, but we can make some estimates that can be used until we gather facts.

Effects on other users

per well is about the same as that proposed by Utah Construction and Mining Co., but the yield per section could be evaluated as almost 10 times that proposed for the new wells. It should be mentioned here that although the Colorado River was close enough to be supplying some recharge to the Navajo in the vicinity of the Merritt-Chapman and Scott Corp. wells, the static water levels in the wells were about 160 to almost 190 feet above the water in the river, appreciably more than the normal drawdowns of the wells during pumping. It would appear, therefore, that the wells planned by Utah Construction and Mining Co. should be able to sustain the planned yield from a saturated aquifer.

Now, to answer the question about the effect on other water users. Removal of water from the Navajo at a rate greater than natural recharge eventually will have some effect on the yield of springs from the Navajo, but many of these wells are so far from the areas of discharge that the effect may not be noticed for decades. The relationship of the springs to the more-distant wells and the possible effect are best illustrated by a diagram (fig. 10).

Effects in well field

The Merritt-Chapman and Scott Corp. drilled six wells into the Navajo in the vicinity of Glen Canyon Dam in a much tighter configuration than that proposed by Utah Construction and Mining Co., and these wells reportedly yielded an aggregate of about 5000 gpm for a period of about $2\frac{1}{2}$ years (Goode, 1964, p. 60) without excessive drawdown. This yield is equivalent to about 1.85 cfs per well, and these wells were in a line stretched over a distance of about $1\frac{1}{3}$ miles. The yield

Precautions

Wells drilled near the coal deposits probably would not affect the springs for some decades; wells drilled in the recharge area close to the springs probably would soon decrease the flow of and eventually dry up the springs. However, these effects can be anticipated for springs that are in the vicinity of proposed wells, say within a mile or two, and if flow measurements are made on the springs before, during, and after pumping, bad effects can be detected and evaluated.

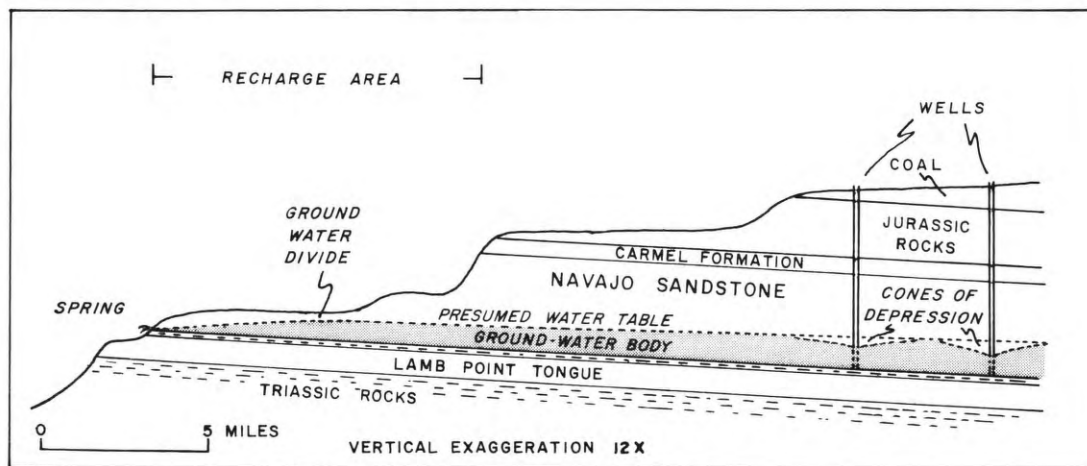


Figure 10. — Schematic diagram to show that pumping of distant wells will not affect spring flow. As long as ground-water divide is higher than springs, springs will flow. If a cone of depression were to extend to and lower ground-water divide, yield of spring would diminish. (Vertical exaggeration applies only to thickness of beds — dip of 3° is approximately correct.)

Table 5. — Chemical analyses of 48 samples of water from 36 springs, 1 creek, and 3 wells.

47 samples were collected in Kane County, 1 sample in Garfield County. Analyses are grouped by principal drainages, which are listed from west to east; within groups analyses are listed in downstream order. An asterisk (*) in any column refers to further information in Remarks. Flow: E = estimated; M = measured; R = reported; gpm = gallons per minute. All analyses by State Chemist, Department of Agriculture, State of Utah.

Reference number on map, figure 2	Name, owner, or other identification	Spring or well coordinate number 1/	Date collected (All 1964 unless noted)	Temperature of	Parts Per Million													pH	Field sample number	Probable source formation (See table 1 for symbols)	Flow or yield (gpm)	Remarks
					Silica (SiO ₂)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium & Potassium (Na + K)	Alkalinity (as Ca CO ₃)	Sulfate (SO ₄)	Chloride (Cl)	Fluoride (F) 2/	Nitrate (NO ₃)	Total dissolved solids (Evaporated at 105°C)	Total hardness (as Ca CO ₃)						
SPRINGS AND SURFACE WATER																						
East Fork Virgin River																						
90	Campground spring US89	(C-39-7)36acb	7-20-63	57	5.6	0.06	30	12	8.1	125	6.1	8		None	145	124		Order 7	Kw	0.8 M	This analysis published also in WR Bull. 5	
90	Campground spring US89	(C-39-7)36acb	Aug. 30	57	6.5	0.07	30	13	7.4	125	8.8	5	0.55	None	150	126	8.0	Cret 17	Kw			
90	Campground spring US89	(C-39-7)36acb	3-21-65	46	4.0	0.12	33	14	6.3	130	14	4		None	168	140	7.3	Cret 17A	Kw			
91	Hidden Lake	(C-40-7)11dbb	3-21-65	52	6.4	0.52	52	19	47	305	9.0	47		None	328	208	7.9	Order 2A			74° at end of discharge pipe	
92	Dr. Thomas' west spring	(C-40-7)10dad	3-21-65	46	8.3	0.24	55	26	9.2	200	56	6		None	298	243	7.9	Order 3A				
2	Yellowjacket No. 2	(C-42-8)36ddc	July 19	*	13	0.09	40	11	4.4	145	8.3	6		8.3	191	147	7.3	Nav 1	J ^R n	< 1/4 E		
3	Harris Springs	(C-43-8)9dbb & dbc	July 19	67	10	0.05	51	13	11	185	9.1	8		None	224	179	7.6	Nav 2	J ^R n	3 E		
Lower Kanab Creek																						
6	Upper Cottonwood (west of Kanab Creek)	(C-43-7)3ccc	July 27	55	9.9	0.04	42	12	2.0	155	4.1	8		0.5	176	154	7.7	Nav 9	J ^R n	10 E	15 gpm M plus 3 gpm E	
		(C-43-7)3ccc	3-22-65	51	8.5	0.01	33	11	8.0	135	4.2	6		5.5	153	130		Nav 9A	J ^R n			
8	Farm Canyon No. 1	(C-43-7)9dbd	July 27	54	9.6	0.04	27	2.7	15	120	2.9	6		2.0	138	78	7.7	Nav 8	J ^R n	18 E*		
8	Farm Canyon No. 1	(C-43-7)9dbd	3-22-65	52	6.2	0.43	26	9.8	12	117	2.0	6		2.0	127	106	8.0	Nav 8A	J ^R n			
12	Water Canyon No. 2	(C-43-7)16ddd	Aug. 5	58	10	0.03	49	15	13	195	6.8	10	0.35	None	220	183	7.7	Nav 11	J ^R n	150 E	25 gpm where sampled	
15	Lower headwaters	(C-42-6)4ccc	Aug. 1	58	7.5	0.04	58	52	24	245	142	14		1.0	508	358	7.7	Nav 10	J ^R n	100 E*		
Johnson Canyon																						
19	Bald Knoll Hollow	(C-40-5)11	Aug. 25	56	4.1	0.03	77	55	28	340	125	8		None	563	417	7.9	Cret 15	Ksc	2-3 E	About 200 ft from spring	
20	Thompson Creek	(C-40-5)11	Aug. 25	57	3.1	0.04	87	64	22	340	167	12		None	616	482	7.6	Cret 16	Ksc?	2 1/2 M		
22	Left fork, Mill Creek, east pink	(C-39-5)25	July 28	55*	4.0	0.03	43	20	8.4	200	8.5	6		None	214	190	7.4	Cret 2	Kk	30 E*	About 3 gpm where sampled	
23	Left fork, Mill Creek	(C-39-4 1/2)30	July 28	49	3.0	0.02	62	32	24	275	27	8		None	356	286	7.7	Cret 1	Kw?	25-30 E*		
23	Left fork, Mill Creek	(C-39-4 1/2)30	3-22-65	44	2.0	3.35	62	33	7.7	267	15	7		None	320	288	7.7	Cret 1A*	Kw?		Probably sample came from opening different from that which yielded Cret 1 Sampled at north orifice	
28	Tennys meadow	(C-39-4 1/2)29	July 30	49	7.7	0.02	67	36	60	330	102	10		None	491	330	7.5	Cret 4	Ksc	25 E*		
32	Meadow Canyon, east headwaters	(C-42-5)36bbd	Aug. 28	57	6.0	0.03	33	18	9.7	155	4.1	12		2.4	187	154	8.1	Nav 14	R ⁿ l	15 E	Part of many springs at canyon mouth	
34	Johnson house spring	(C-42-5)35adb	Aug. 28	67	12	0.04	36	13	5.7	130	9.8	12		4.6	187	143	7.6	Nav 15	R ⁿ l	1/4 E		
36	Dairy Canyon, south side	(C-42-5)35cbd*	Aug. 29	56	10	0.04	51	23	18	160	83	12		2.2	324	222	7.8	Nav 16	R ⁿ l(or fault?)	200-400 E		
45	Johnson Lakes, headwaters	(C-42-4 1/2)32dab & dba	Aug. 28	62	6.7	0.04	37	20	14	185	9.6	11		None	222	185	7.8	Nav 12	R ⁿ l		Part of several springs	
46	Johnson Lakes, pipe spring	(C-42-4 1/2)32dcb	Aug. 28	58	3.6	0.03	39	24	11	195	12	12		5.2	254	197	8.4	Nav 13	R ⁿ l	14 M		
48	Johnson Lakes, Flood Canyon	(C-43-4 1/2)8bbb*	Aug. 27	59	11	0.05	63	49	28	365	17	28		None	433	358	8.1	M-6	R ^k ?	23 M		

Reference number on map, figure 2.	Name, owner, or other identification	Spring or well coordinate number 1/	Date collected (All 1964 unless noted)	Temperature of	Parts Per Million												pH	Field sample number	Probable source formation (See table 1 for symbols)	Flow or yield (gpm)	Remarks
					Silica (SiO ₂)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium & Potassium (Na + K)	Alkalinity (as Ca CO ₃)	Sulfate (SO ₄)	Chloride (Cl)	Fluoride (F) 2/	Nitrate (NO ₃)	Total dissolved solids (Evaporated at 105°C)	Total hardness (as Ca CO ₃)					
SPRINGS AND SURFACE WATER - Continued																					
Kaibab Gulch (Buckskin Gulch)																					
50	Slide Canyon, right pink	(C-39-4½)16	July 30	62*	4.1	0.03	43	49	16	255	75	10		None	373	309	8.1	Cret 3	Kk	1/8 M	Temperature about 60 yds from source
55	Crawford Pass, middle spring	(C-39-4)7	Aug. 22	50	4.6	0.04	71	36	5.6	325	5.4	7		None	354	326	8.1	Cret 13	Kk	2½ M	
57	Meadow, north	(C-39-4)18	Aug. 22		1.7	0.07	64	30	7.5	245	43	8		None	309	283	8.0	Cret 14	Kw?	3 E	
59	Pipeline Canyon	(C-39-4)16	Aug. 21	48	3.3	0.04	71	29	4.7	295	5.7	6		None	317	296	8.0	Cret 12	Kk	1-2E	
61	Meadow, main	(C-39-4)19 & 20	Aug. 20	48*	5.5	0.03	92	19	39	385	33	8		None	456	309	7.4	Cret 11	Kw?	100 E*	Several openings; also recorded 46° Probably sample came from opening different from that which yielded Cret 11
61	Meadow, main	(C-39-4)19 & 20	3-22-65	43	4.3	0.03	93	48	9.9	395	46	10		None	480	431	7.5	Cret 11A*	Kw?		
67	Riggs Spring	(C-38-4)33	Aug. 20	45	4.0	0.03	104	52	37	510	43	13		None	583	475	7.8	Cret 8	Kk?	1+ M	
68	Riggs Creek, north	(C-39-4)11bbc	Aug. 20	49	7.2	0.04	123	74	15	455	170	11		None	758	612	7.6	Cret 9	Ksc	6½ M	
70	Riggs Creek, Brown Ranch	(C-39-4)13bbc	Aug. 20	52	1.4	0.04	56	56	20	295	105	9		None	476	370	8.3	Cret 10	Ksc	10 E	
73	Kitchen Corral Point	(C-41-3)34cbb	Aug. 26	74	9.4	0.04	15	10	181	270	216	50		None	680	78	8.7	M-5	*	¼ M	R (on fault?)
73	Kitchen Corral Point	(C-41-3)34cbb	3-22-65	51	8.1	0.02	13	10	195	240	211	49		None	691	72	8.2	M-5A	*		R (on fault?)
Paria River																					
75	Pine Spring (Indian spr.)	(C-39-3)10	Aug. 4	58	11	0.03	98	47	28	260	210	16		None	628	440	8.0	M-2	Jw?	¼ M	Recorded 50° 100 yds east of sampling point Qal (Jw?)
78	Willis Creek, headwaters	(C-38-4)11cdb	Aug. 13	56*	2.8	0.03	86	58	20	355	122	11		None	560	452	7.6	Cret 7	Qal (Ksc?)	50 E	
80	Lower Willis Creek	(C-38-3)16	Aug. 3	55	10	0.07	103	76	109	340	428	15	0.6	None	1086	568	7.5	M-1	*	10 M	
83	Cottonwood No. 6	(C-40-1)11	July 23	62	7.3	0.04	37	6.1	6.5	95	21	10		1.0	165	117	7.3	Nav 7	JRn	8 M	
85	Cottonwood No. 4	(C-40-1)14	July 22	60	9.7	0.05	46	7.1	9.5	130	20	10		1.8	194	144	7.9	Nav 6	JRn	63 M	
86	Cottonwood No. 3	(C-40-1)23 & 14	July 22	60	9.7	0.05	39	12	14	145	20	11	0.3	None	199	148	7.6	Nav 4	*	58 M	Qal (fault in JRn?)
93	Hackberry Creek *	(C-40-1)5	July 21		3.9	0.04	25	25	14	140	41	11		None	215	166	7.8	Nav 3		400 E	Stream sample about 7 mi above mouth
94	Hackberry Creek *	(C-41-1)9	July 22	96	14	0.24	27	28	30	245	49	14		None	276	180	7.8	Nav 5		50 M	Stream sample about ¼ mi above mouth
Henrieville Creek																					
89*	North side U-54	(C-37-1)9bca, bbd	Aug. 12	57	0.8	0.04	68	33	8.1	265	45	8		None	352	304	7.5	Cret 6	Ksc	200 E	Not shown on base map of figure 2
WELLS																					
Johnson Canyon																					
101	Bunting well	(C-42-5)11bda	Aug. 29	56	14	0.07	117	42	24	220	264	16		3.8	738	465	7.8	Nav 17	JRn	600 E *	Pumping
108	Hamblin well	(C-43-4½)31ddd	Aug. 26	58	10	0.13	116	2.9	121	235	273	32		None	714	302	7.8	M-4	R	300-350M*	Flowing
Kaibab Gulch																					
112	Findlay ranch well	(C-40-4)14	Aug. 20	51	6.6	0.04	80	85.4	33	380	214	15	0.3	2.1	806	549	8.0	M-3	Qal	20 E *	Pumping

- Coordinates are given only for springs and wells that are in areas covered by published U. S. Geological Survey topographic maps. Approximate coordinates for other springs and wells can be obtained from locations shown on figure 2 and from T., R., and section given here.
- Fluoride determinations made only on five samples.

Chemical Quality of Water from Springs and Wells

Summary of chemical quality

The waters of Kane County have wide ranges in chemical quality: chemical analyses given in this report (table 5) and reported earlier in Water-Resources Bulletin 5 show that 1) water from springs in the Navajo Sandstone generally contains less than 250 ppm (parts per million) total solids and is hard to moderately hard (197 to 78 ppm hardness); 2) water from wells in the Navajo has been reported to have as much as 3100 ppm total solids, but generally has less than 900 ppm; 3) waters from springs in the Cretaceous sandstones contain 200 to 700 ppm total solids and are very hard (190 to 540 ppm hardness); and 4) waters from springs and wells in other formations contain 625 to nearly 1100 ppm total solids and, with but one exception (sample M-5, table 5), are very hard (300 to 570 ppm hardness).

All natural waters contain dissolved mineral matter which has been picked up as the waters percolate through the ground as ground water or flow over the surface of the ground as surface water. The kinds and amounts of minerals dissolved by surface or ground water depend on the kinds and solubility of the minerals in the adjacent rocks and soils, and on the length of time the water is in contact with soluble mineral matter.

Some of the most common elements or ions dissolved in natural water are: 1) calcium and magnesium carbonates dissolved principally from limestone and dolomite and expressed in the analyses as calcium, magnesium, and carbonate (or bicarbonate); 2) sodium and potassium sulfates and chlorides, derived from sodium chloride and from sodium, potassium, or calcium sulfate, and expressed as sodium plus potassium, and sulfate and chloride; 3) silica derived from silicate minerals in sandstone or in metamorphic or igneous rocks; 4) iron derived from iron-bearing minerals; and 5) nitrate, derived chiefly from the oxidation of organic matter or from fertilizers. Other less abundant constituents of natural water are fluoride, boron, and metallic elements such as lead, zinc, copper, and uranium.

Two convenient methods of comparing waters are by means of hardness and total dissolved solids. Hardness is a quality of water that is readily recognized because hard water requires a greater quantity of soap to produce lather and because it forms scale inside pots and boilers. Water that contains hardness of 60 ppm or less is considered soft; 61 to 120 ppm is moderately hard; 121 to 200 hard;

and over 200 very hard (Connor and others, 1958, p. 23). Total dissolved solids are usually determined by evaporating the measured sample to dryness; the samples recorded on table 5 were evaporated to dryness at 105°C. Water that contains more than 500 ppm total solids is generally considered to be unsuitable for public or domestic supply, but many waters that contain 1000 to 1500 ppm are satisfactory for irrigation use, and some water that contains more than 5,000 ppm total solids may not only be acceptable to some animals but even relished by them. Water that is to be considered for use in electric generating plants probably should contain less than 900 ppm total solids.

In this report general comparisons of the waters are made by comparing amounts of hardness and total solids, but in addition other individual constituents are compared in an attempt to characterize the waters according to their sources.

Table 6 contains ranges of constituents and median values of constituents for waters collected from the Navajo, Straight Cliffs, Wahweap, and Kaiparowits formations. Listed below the median analyses are individual anomalous analyses of waters that were collected from the same formation but that do not "fit" into an array, the pattern set by the other analyses. The constituents that keep the anomalous analyses from fitting into the arrays are underlined, and some explanation is given in the table for each of these anomalous analyses.

Comparison of water from Kaiparowits, Wahweap, Straight Cliffs, and Navajo Formations

A comparison of the arrays for the four formations shows 1) that water from the Navajo contains the least amount of mineral matter but it generally contains more silica (SiO_2) and it is liable to contain nitrate (NO_3), whereas waters from the Cretaceous sandstones do not contain nitrate; 2) that waters from the Kaiparowits and Wahweap are nearly the same except that water from the Wahweap may contain more sulfate (SO_4) than water from the Kaiparowits; and 3) that waters from the Straight Cliffs generally contain more calcium (Ca), magnesium (Mg), and sulfate (SO_4) than waters from the Kaiparowits or Wahweap, and hence may be harder and contain more total solids.

One point is worth emphasizing about the quality of the water from the Navajo. Although water from nearly all springs and from a few wells in the Navajo contains less than 250 ppm total solids, the water from most wells in the Navajo (specifically the principal Merritt-Chapman and Scott wells near Glen Canyon Dam - Goode, 1964, table 7)

Table 6. — Comparison of chemical analyses of water from the Kaiparowits, Wahweap, Straight Cliffs, and Navajo Formations.

Analyses are grouped by formation. Analyses show range of constituents (in parts per million) and median values of constituents of samples that fell into apparent natural arrays. Shown below each group of analyses are anomalous analyses of water from the same formation; italicized are the quantities of constituents that did not fit the array. Analyses labeled Cretaceous and

Navajo show in parentheses the map localities on figure 2. Analyses labeled Alton and Orderville were published in Water-Resources Bulletin 5; analyses labeled Cretaceous and Navajo are in table 5. *The median values shown are medians for each constituent; they do not represent median analyses.

Analyses of water from KAIPAROWITS FORMATION	Ranges of constituents and median values of constituents of 11 samples from Kaiparowits or Kaiparowits(?) Formation Samples included in the array are: from Kaiparowits: Cretaceous 2(22), 3(50), 12(59), 13(55); Alton 2, 8; Orderville 9, 10, 19. from Kaiparowits(?): Cretaceous 8(67); Alton 1.										
		SiO ₂	Ca	Mg	Na + K	SO ₄	NO ₃	Total solids	Hardness	Cl	Additional information about anomalous analyses
	Range	0.8-7.8	43-104	20-52	0.3-39	4.7-75	None	214-583	190-475	6-13	
	Median *	4	65	34	11	10		347	301	8	
	Anomalous Analysis :										
	Alton 3	11.6	62	27	12	2.2	1.5	307	266	9	Alton town supply.
	This sample may have come from a conglomerate in the Wasatch rather than from the Kaiparowits.										
Analyses of water from WAHWEAP FORMATION	Ranges of constituents and median values of constituents of 11 samples from Wahweap or Wahweap(?) Formation Samples included in the array are: from Wahweap: Orderville 2, 3, 11, 12, 16; and from Wahweap(?): Cretaceous 1 and 1A(23), 11 and 11A(61), 14(57); Alton 6.										
		SiO ₂	Ca	Mg	Na + K	SO ₄	NO ₃	Total solids	Hardness	Cl	Additional information about anomalous analyses
	Range	1.4-8	55-97	19-67	6.5-39	None-158	None	292-650	221-538	4-14	
	Median *	5	64	32	19	33		356	288	8	
	Anomalous Analyses :										
	Cret 17(90)	6.5	30	13	7.4	8.8	None	150	126	5	} Campground on US 89.
	Cret 17A	4.0	33	14	6.3	14.	None	168	140	4	
	Order 7	5.6	30	12	8.1	6.1	None	145	124	8	
	These samples are all from the same spring which may receive its recharge from precipitation on the adjacent ridge, or from some other unknown source.										
	Order 4	7.6	35	13	9.7	6.7	None	180	140	10	Big Spring, Lydias Canyon.
This analysis is similar enough to analyses from the campground spring (above) for the waters from both to have a common source; that source is not known.											
Order 15	6.0	117	57	27	196	None	690	527	9	Spring in Calf Pasture Hollow.	
This water may get its high calcium (Ca) and sulfate (SO ₄) from a local bed of gypsum.											
Analyses of water from STRAIGHT CLIFFS FORMATION	Ranges of constituents and median values of constituents of 5 samples from Straight Cliffs or Straight Cliffs(?) Formation Samples included in the array are: from Straight Cliffs: Cretaceous 10(70), 15(19); and from Straight Cliffs(?): Cretaceous 4(28), 7(78), 16(20).										
		SiO ₂	Ca	Mg	Na + K	SO ₄	NO ₃	Total solids	Hardness	Cl	Additional information about anomalous analyses
	Range	1.4-7.7	56-87	36-64	20-60	102-167	None	476-616	330-482	8-12	
	Median *	3.1	77	56	22	122		560	417	10	
	Anomalous Analyses										
	Cret 9(68)	7.2	123	74	15	170	None	758	612	11	Riggs Creek.
	This sample may have come from the Tropic Shale rather than the Straight Cliffs.										
	Cret 6	0.8	68	33	8.1	45	None	352	304	6	Henrieville Creek.
	No explanation: This water is better than any water collected from Straight Cliffs west of this locality.										
	Analyses of water from NAVAJO SANDSTONE	Ranges of constituents and median values of constituents of 16 samples from Navajo Sandstone Samples included in array are: Navajo 1(2), 2(3), 3(93), 4(86), 6(85), 7(83), 8 and 8A(8), 9 and 9A(6), 11(12), 12(45), 13(46), 14(32), 15(34); Alton 7.									
		SiO ₂	Ca	Mg	Na + K	SO ₄	NO ₃	Total solids	Hardness	Cl	Additional information about anomalous analyses
Range		3.6-13	25-51	2.7-25	2.0-15	2.0-41	None-8.3	127-254	78-197	6-16	
Median *		9	37	13	11	9	2.0	192	147	10	
Anomalous Analyses											
Navajo 5(94)		14	27	28	30	45	None	276	180	14	Surface water, Hackberry Creek.
This sample was collected more than 5 miles from source and might be expected to have constituents different from most samples from Navajo.											
Navajo 10(15)		7.5	58	52	24	142	1.0	508	358	14	Probably on fault in Johnson Can.
Navajo 16(36)		10	51	23	18	83	2.2	324	222	12	Possibly on fault in Johnson Can.
These samples came from springs that probably or possibly are on faults.											
Navajo 17(101)	13.8	117	42	24	264	3.8	738	465	16	Bunting well in Johnson Canyon.	
This water may be coming from a fault.											

contains from 750 to 1000 ppm. The few data available on water from deep wells in the Navajo in Kane County suggest that the water in deep storage may be of appreciably poorer quality than the water coming from springs. Plans to develop the aquifer should consider that note of caution.

Future Development of Ground Water

Future development of ground water in western Kane County depends on the demand for that water. My studies suggest that there are large quantities of water, estimated at 10 to 20 million acre-feet, in storage in the Navajo Sandstone at depths ranging from a few hundred feet in the vicinity of Johnson Canyon to 4000 feet or more in the vicinity of Alton. The presence of water in the Navajo in western Kane County has been proven by the successful wells that have been drilled in Three Lakes Canyon and Johnson Canyon; the full extent of the ground-water body in the Navajo can be determined only by additional drilling. Completion of a few test wells in some of the sections in Township 40 South, under the application of Utah Construction and Mining Co. (fig. 2), would make it possible to test the thickness of the saturated zones in the Navajo, determine hydraulic properties of the rocks, and collect samples of water for analysis. (See also caution on quality of water in the Navajo at the end of the section on quality of water.) Only a few such tests would be required to determine the feasibility of continuing the program.

If test drilling verifies my estimates of storage in the Navajo, development of that aquifer can be based on either of two policies: 1) the safe-yield policy, in which the amount withdrawn from the aquifer each year does not exceed the average annual effective recharge (comparable to rejected recharge in the barrel analogy of figure 6) which is estimated for the Navajo at 30,000 to 60,000 acre-feet a year, or 2) the mining policy which implies that no attention will be paid to the amount of recharge, but rather that the development will take water out of storage. Development under the safe-yield policy is the only kind of development that will permit long-term use of an aquifer, but development by mining may be warranted if it is recognized that the amount of water in storage has limits and that whatever endeavor is based on the water supply will come to an end when the supply is depleted. In this country both policies are followed: municipalities that depend on ground water attempt to develop aquifers that have recharge sufficient for their needs; but irrigation in many

parts of Texas and Arizona and in some parts of Utah is based on taking out of the ground each year much more water than is returned to it. In Kane County the development of water under the mining policy might permit the development of a resource, coal for power generation, that would not be developed if the water is kept in the ground.

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*Policy
for
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GLOSSARY

The definitions given herein were compiled from many sources. Those that are quoted were taken from:

Meinzer, O. E., 1923, Outline of ground-water hydrology, with definitions: U.S. Geol. Survey Water-Supply Paper 494, 71 p.

Langbein, W. B., and Iseri, K. T., 1960, General introduction and hydrologic definitions, Manual of Hydrology: Part 1: U.S. Geol. Survey Water-Supply Paper 1541-A, p. 1-29.

Abbreviations and definitions of units of measurement

acre-foot. Amount of water that will cover one acre to a depth of one foot. Equivalent to 325,850 gallons.

cfs. Cubic foot (feet) per second. A flow of one cubic foot past a given point each second. Equivalent to 448.83 U.S. gallons per minute, 1.98 acre-feet per day, or 724 acre-feet per year.

cubic foot. Equivalent to 7.4805 U.S. gallons.

gallon. Equivalent to 0.13368 cubic foot.

gpm. Gallon(s) per minute - A flow of one gallon past a given point each minute. A million gallons is slightly more than 3 acre-feet.

ppm. Parts per million. Quantitative term used to express ratio of weight of dissolved (or suspended) minerals to weight of one million parts of water and dissolved (or suspended) solids.

Definitions of hydrologic terms

aquifer. A rock formation, a group of formations, or part of a formation that is water bearing and will yield that water to wells. (The connotation here is that some water-bearing units, such as clays, are so fine grained that they will not yield their water readily and therefore are not properly called aquifers.) See also: artesian aquifer, water-table aquifer.

artesian aquifer. A water-bearing formation whose water is confined by an overlying less-permeable or impermeable stratum. The pressure within an artesian aquifer usually comes from some part of the aquifer, generally the recharge area, where the water level is appreciably higher than the base of the confining bed.

artesian spring. A spring "whose water issues under artesian pressure, generally through some fissure or other opening in the confining bed that overlies the aquifer" (Meinzer, 1923, p. 51).

cone of depression. A depression, roughly the shape of an inverted cone, that is produced in the water table (top of the ground-water body) by pumping. The depression is the result of the removal of water from the aquifer.

cone of pressure relief. A depression, roughly the shape of an inverted cone, that is produced in the piezometric surface of an artesian ground-water body by pumping or by natural flow. The cone of pressure relief represents a change of pressure within the aquifer, not a dewatered portion of the aquifer. Because this cone is a result of release of pressure rather than removal of water, the withdrawal of water from an artesian aquifer produces a cone of pressure relief that is many times larger than the cone of depression produced by the withdrawal of an equal volume of water from a water-table aquifer.

contact spring. A spring "whose water flows to the surface from permeable material over the outcrop of less permeable or impermeable material that retards or prevents the downward percolation of the ground water and thus deflects it to the surface" (Meinzer, 1923, p. 51).

dip. The angle between a horizontal plane and a rock stratum that is not horizontal. Sedimentary rocks generally are deposited as nearly horizontal units. If they were not originally completely horizontal or if they later became tilted, the deviation from the horizontal is called dip.

discharge. Outflow. It may be applied to the natural outflow of springs and seeps, to the natural outflow of flowing wells, to the pumping outflow of non-flowing wells, to streamflow, or to outflow from ditches and canals.

evaporation. Water returned to the atmosphere by vaporization that takes place at a temperature below the boiling point.

evapotranspiration. "Water withdrawn from a land area by evaporation from water surfaces and moist soil and plant transpiration" (Langbein and Iseri, 1960, p. 9).

ground water. All water in the zone of saturation (Meinzer, 1923, p. 5).

ground-water divide. "A line on a water table on each side of which the water table slopes downward in a direction away from the line. *** It is analogous to a divide between two drainage basins on a land surface" (Meinzer, 1923, p. 34).

ground-water runoff. "That part of the runoff which has passed into the ground, has become ground water, and has been discharged into a stream channel as spring or seepage water." Base runoff is essentially the same as ground-water runoff (Langbein and Iseri, 1960, p. 12).

headwaters spring. A spring that provides the initial (generally topographically highest) ground-water runoff in a stream channel or drainage system. The channel above a headwaters spring normally carries only surface runoff. In Kane County some drainage systems have two sets of headwaters springs because the normal yield of the upper headwaters springs is used up in the upper reaches. Hence springs that rise lower in the system are truly headwaters springs because they provide base runoff below dry channels.

perennial flow. Flow that continues throughout a normal year. In Kane County, as in other semiarid and arid areas, the only streams that have perennial flow are those that receive ground-water runoff from springs and seeps.

permeability. The ability to transmit fluids. It is a property that is dependent on the size of and interconnections between pores as well as total pore space. Water-bearing rocks must be permeable if they are to yield water to wells.

piezometric surface. The imaginary surface to which water in a confined (artesian) aquifer will rise under its full head. Aquifers whose piezometric surfaces are above land surface will support flowing wells.

porosity. The ability to contain fluids. It is dependent on the pore space and is measured as the ratio of total pore space to total volume.

precipitation. The natural discharge of water from the atmosphere. It "includes rainfall, snow, hail, and sleet" (Langbein and Iseri, 1960, p. 15).

recharge. "Recharge of ground water comprises the processes by which water is absorbed and is added to the zone of saturation" (Meinzer, 1923, p. 46).

rejected recharge. That water which is prevented from being recharge because the aquifer is full or because the recharge area cannot absorb the water at the rate it is applied. If recharge taken into an aquifer forces the aquifer to overflow at some other point, the overflow can be likened to rejected recharge.

runoff. "That part of the precipitation that appears in surface streams. It is the same as streamflow unaffected by artificial diversions, storage, or works of man in or on the stream channels" (Langbein and Iseri, 1960, p. 17).

seep. Any water-yielding area whose water appears at the surface without discernable movement. Commonly seeps cover only small areas.

seepage area. "Any considerable area in which water is seeping to the surface" (Meinzer, 1923, p. 50).

soil moisture. "Water diffused in the soil, the upper part of the zone of aeration, from which water is discharged by the transpiration of plants or by soil evaporation" (Langbein and Iseri, 1960, p. 17).

spring. "A place where, without the agency of man, water flows from the rock or soil upon the land or into a body of surface water" (Meinzer, 1923, p. 48). See also: artesian spring, contact spring, seep.

streamflow. "The discharge that occurs in a natural channel. *** The term 'streamflow' is more general than runoff, as streamflow may be applied to discharge whether or not it is affected by diversion or regulation" (Langbein and Iseri, 1960, p. 19).

subsurface water. All water that occurs below the surface. It includes water in the zone of soil moisture, water in the capillary fringe, and ground water.

surface water. Any water on the surface of the land.

transpiration. "The quantity of water absorbed and transpired (returned to atmosphere) and used directly in the building of plant tissue, in a given time" (Langbein and Iseri, 1960, p. 20).

water table. The top of the zone of saturation where that zone is not confined by a poorly permeable or impermeable formation.

water-table aquifer. A water-bearing formation whose water is free to move under the force of gravity. Its upper surface is the water table.

water yield. The runoff from a drainage basin. It includes surface water in the stream channel and ground-water outflow that does not appear in the stream channel. "Water yield is the precipitation minus the evapotranspiration" (Langbein and Iseri, 1960, p. 21).

zone of saturation. The zone where all pores and interstices in the rocks are filled with water. Where the zone of saturation is not confined by a poorly permeable or impermeable bed, the top of the zone is called the water table.