OZAR

# WATER RESOURCES OF THE CURRENT RIVER BASIN, MISSOURI


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Geologist

Water Resources Research Center

University of Missouri - Rolla


Final Report of an Investigation from September 1971 to December 1972


Prepared
for the
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CONTENTS

# Section I

## INTRODUCTION

This study was initiated to investigate the general hydrology and water resources of the Current River Basin, a sparsely populated, scenic area of the south-central Missouri Ozarks. A prominent geological feature of the basin is its typical karst topography of large springs, caves, and sinkholes. The studies described here cover an eighteen month period ending December 1972, and are reported as of that date.

The Current River Basin is experiencing rapid growth because of tourism and a consequent strain on all of its resources. The 113 square miles of the Ozark National Scenic Riverways is a focal point for tourists to the area. Clark National Forest and Mark Twain National Forest are partially included in the basin. Former state parks at Round Spring, Alley Spring and Big Spring, which have long been important regional tourist attractions, are being expanded as part of the Ozark Scenic Riverways. Similar inclusion is planned for Montauk State Park near the head of the Current River.

More than a billion gallons of water gush daily from the Current River Basin's uniquely beautiful springs. Should these springs become contaminated or polluted, irreparable damage would be done to the Current and Jacks Fork rivers. Concern for the sources of these springs is one of the central themes of this report.

After a brief survey of the geographic and demographic patterns of the Current River area (Section II), this report focuses on a compilation

of existing sources of data of the quantity and quality of water in the Basin. Most of these data are contained in Water Supply Papers published by the United States Geological Survey. Section III includes comprehensive lists of the pertinent papers.

In a separate but closely related study by Miss Susan Blickensderfer made available for the first time in this report, the relationship between rainfall and surface streamflow from several subdivisions of the Basin was examined. Ten years of rainfall and discharge data were analyzed to derive equations which may ultimately aid in monitoring the effects of human activity in the Basin.

The inter-relationship between use and abuse of the Current River Basin's water resources must be stressed as a continuing, reciprocal two-way relationship. Tourists are attracted to this beautiful, forested area in large part because of its relatively pure water. However, as noted in the study, there are, even now, potential sources of pollution from inadequate sewage disposal, sinkholes used as garbage dumps and as drains for cattle lands, and from mining development. However, even as these pollution sources are appraised (and hopefully eliminated), the huge influx of tourists who are camping, fishing, boating and hunting introduces new pollution potentialities which can be handled only by careful pre-planning.

Section V describes two major groundwater tracing studies undertaken for this report. One investigated the spring sources in the northern and northeastern half of the Current River basin and was done by Dr. Maxwell and Mr. David Hoffman. The other tracer study concentrated on Big Spring and the southern half of the basin and was done by Mr. Thomas Aley, hydrologist for the Ozark Underground Laboratory.

Determination of the bacteriological quality of water from the Current and Jacks Fork Rivers was the primary aim of two projects undertaken during June, July, and August 1972. (See Section VI.) One study was summer-long and consisted of water sampling, at ten-day intervals, at sixteen different sites, four on the upper Current, seven on Jacks Fork, and five in the lower Current. The second, an intensive study, was conducted during the Independence Day weekend to determine the impact of holiday visitors. More than four hundred water samples were collected and more than twelve hundred bacteriological test plates were analyzed for this project.

The material contained in this report should serve as background and source for any future work on the water resources of the Current River basin.

# Section II

## GEOGRAPHY AND DEMOGRAPHY

The Current River Basin is a sparsely populated area in the South-Central Missouri Ozarks that includes all or parts of Dent, Texas, Howell, Carter, Ripley, and Shannon counties and a small part of Reynolds County. As shown in Figure 2-1, it is bounded by Missouri Highways 32, 72, and 21, and U. S. Highways 63 and 60. Missouri Route 19 is the major north-south artery through the basin. U. S. 60 is the major east-west highway and gives Springfield, Missouri residents good access (Springfield-Van Buren, 150 miles). Western portions of the state are served by Missouri Route 17. St. Louis area residents are served by U. S. 67 and Interstate 55 (St. Louis-Van Buren, 170 miles).

The 113 square miles of the Ozark National Scenic Riverways is only five and one half percent of the 2038 square miles of the Current River Basin above Doniphan, Missouri. However, most of the regional tourist traffic gravitates to the recreational facilities in and around the Current and Jacks Fork Rivers. The headquarters of the Riverways is in Van Buren.

Clark National Forest to the north and Mark Twain National Forest to the south are also partially included in the Current River Basin. Big Spring, Round Spring, and Alley Spring are the major developed areas within the boundaries of the Riverways. Montauk State Park adjoins the northern boundary of the Riverways (Bevins and Davis, 1969, p. 15).

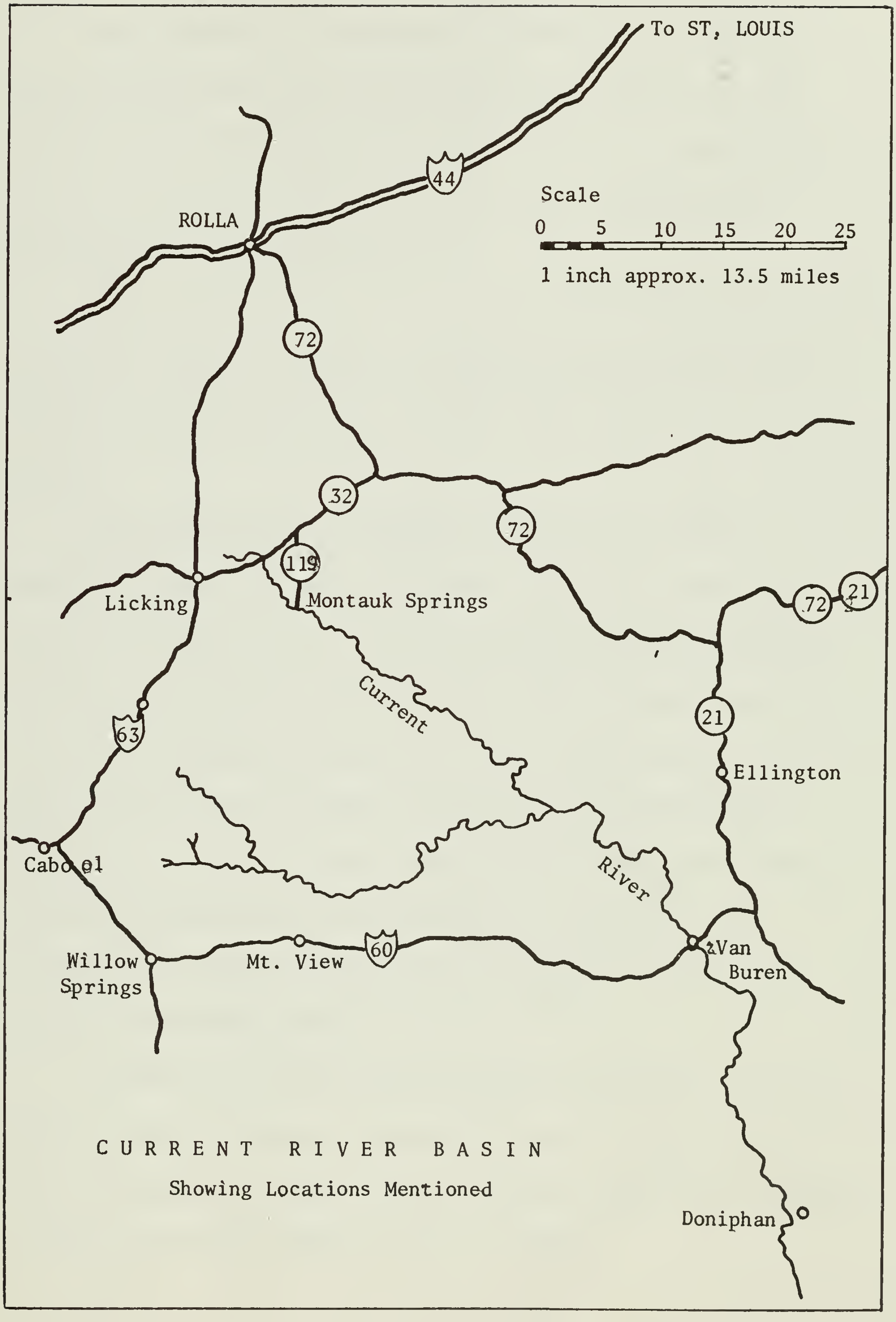
To ST, LOUIS
44
Scale
0 5 10 15 20 25
1 inch approx. 13.5 miles
ROLLA
72
32
72
119
Licking
Montauk Springs
72
21
Current
21
Ellington
63
Cabool
River
Willow
Springs
Mt. View
60
Van
Buren
CURRENT RIVER BASIN
Showing Locations Mentioned
Doniphan

Figure 2-1

About 80 percent of the land in the Ozark National Riverways is in Shannon County (National Park Service, 1960, p. 49). Based on the 1970 Missouri census, Texas County is the most populous of the counties (18,320 permanent residents) and Carter County is the least populated (3,878). Shannon County had 7,196 residents in 1970.

The seven counties in and around the Current River Basin are shown in Figure 2-2. Maps of each country, detailing the 1970 population of each township and the most populous town in each township, are at the end of this section.

The largest towns in and adjacent to the Current River Basin are West Plains, Salem, Houston, and Van Buren. (West Plains, Salem, and Houston are on the periphery.) Because Van Buren, the largest town within the basin, has a population of only 714 (1970 census), it is readily apparent that the area is very sparsely populated. Because of their location on the major, regional, east-west highway, it can be predicted that the towns of Mountain View, Birch Tree, Winona, and Van Buren will experience rapid industrial and tourism growth in the next few years. Eminence, at the intersection of the central Riverway access highways, will probably benefit most from the growth of tourism.

The barren, rocky soils of the area have been a hindrance to farming, and consequently many people in the area are forced to earn a livelihood from "timber scrapping" -- cutting the immature growth of timber. Others engage in subsistence agriculture (National Park Service, 1960).

# COUNTY INDEX

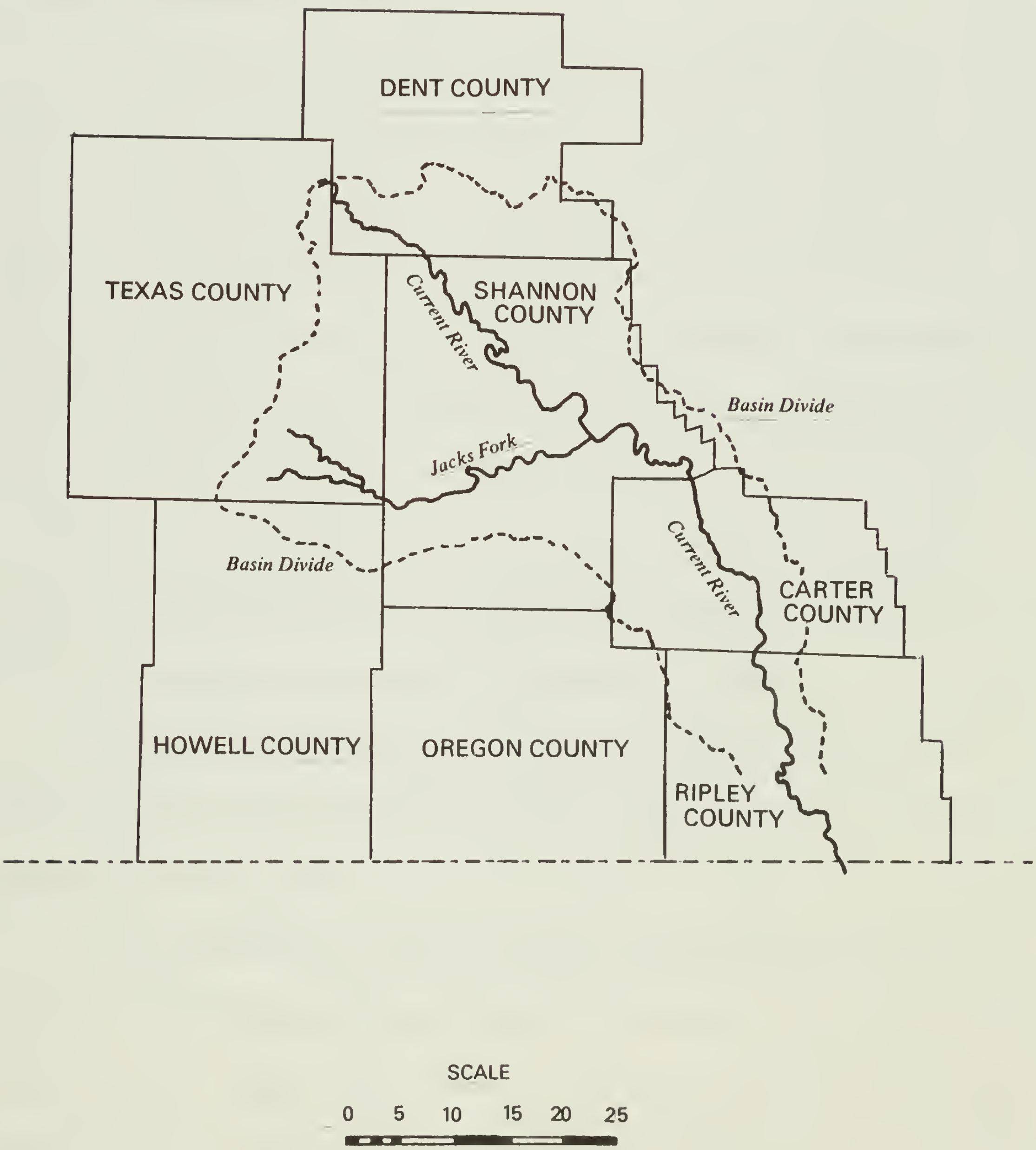


Figure 2-2

The Ozark National Riverways, with its encouragement of outdoor recreation and tourism and the consequent improved employment opportunities, has undoubtedly improved the economic well-being of the people in this area. Future population characteristic studies would be helpful in gauging the impact of this Federal undertaking on the lives of the people in the region, with particular emphasis on income levels.

The Department of the Interior estimated that in 1971 a total of 2,900,000 persons visited the Riverways zones, mostly in Shannon and Carter counties (Leeman, 1972). It was estimated by the Missouri State Highway Department that in 1970 there were a total of 5,321,400 visits to the Riverways (Anonymous, 1970, p. 13). (The discrepancy in these figures is due to the methods used to distinguish between persons and visits. The latter may include multiple counting of the same people as they go in and out of the area.) Compared to the total number of visits and visitors, the number of people who actually floated the Current and Jacks Fork Rivers in 1970 is rather small, approximately 122,000 (Marnell, 1972).

The Missouri Highway Department estimates that by 1990 the total number of visits to the Ozark National Scenic Riverways will be 17,617,800 (Anonymous, 1970, p. 15).

At the present time, about 72 percent of visits to the area are from Missouri, with 63 percent of these coming from the study area. It is expected that the majority of new visitors to the area will come from states other than Missouri and that by 1990 two-thirds of the visitors will come from outside the

state. California, Illinois, and Arkansas are expected to contribute significantly to these future totals (Anonymous, 1970).

Most visits to the area are made in the summer months of June, July, and August, with attendance peaking in July. However, there is visitation year round with some outdoorsmen floating the Current River even in January. Randall R. Pope, superintendent of Ozark National Scenic Riverways, notes "one thing for sure about winter canoeing--it is completely devoid of congestion" (Leeman, 1972).

According to records of the Missouri State Park Board, in 1968 there were 1,120,000 visitors to the four state parks in the area: Alley Spring, Big Spring, Montauk, and Round Spring. Because of their beauty and recreational facilities, these parks will probably continue as major tourist attractions (Bevins and Davis, 1969, p. 9).

Since there are, to date, few motels in the area, most summer-time overniters are accomodated by recreational camping. Families and individuals come to float the rivers, fish, wade, and swim. Boating is permitted and, more unusual for lands under National Park Service control, hunting too is permitted, although it is subject to necessary safety measures and State and Federal control (Bevins and Davis, 1969, p. 4).

The Division of Planning of the Missouri State Highway Department estimates that by 1990 there will be vastly increased use of the feeder highways. U. S. Route 60, the area's major east-west highway, carried about 1,600 vehicles in 1969, and is expected to carry around 6,000 vehicles daily in 1990.

Traffic on this route during the summer months of June, July, and August is projected to increase to the 11,000 to 12,000 per day range in 1990 (Anonymous, 1970, p. 31).

The major north-south artery, Missouri Route 19, is expected to have an average daily traffic in excess of 2,000 in 1990, with the daily average in the summer estimated in the 4,000 to 4,500 range. The average daily traffic on Missouri Route 17 is expected to be around 2,700 vehicles, whereas a summer average of over 5,000 is indicated. Other supplementary routes which serve the area should have average daily traffic figures of around 400 or 600 vehicles (Anonymous, 1970).

At the present time, there are lodging, eating, and other accomodations and services in nearby cities and towns. Campsites are available in four areas within the Riverway: Pulltite, between Akers and Round Spring; Round Spring, 13 miles north of Eminence and 30 miles south of Salem; Alley Spring near Eminence; and Big Spring near Van Buren. Montauk State Park, adjoining the north end of the Riverways, also has public campgrounds. In addition, there are privately owned campgrounds within and adjacent to the Riverways. Floaters frequently camp on the many gravel bars found along the river. There are plans to provide additional primitive and improved campsites along the rivers. These will be accessible only by boat.

The expected increase in visitors will undoubtedly encourage newcomers to seek jobs in the motels, restaurants, and other service type business that will be enlarged or established to serve tourists. Job availability will encourage

more people to settle permanently in the Current River Basin. Consequently all towns in the basin should experience population increases.

At the present time, West Plains, the largest town on the periphery of the Current River Basin, has a population of 6,893 (1970 census). Salem, on the northern periphery, has a population of 4,363 (1970 census). There are 22 towns in the basin area (including Salem and West Plains) that are large enough to have Mayors (Goodwin, 1970).

Salem is already a large tourist center for those entering or leaving the Current River Basin. It has four motels and seven restaurants. West Plains has four motels, 16 restaurants.

Eminence, at the intersection of Highways 19 and 106, is centrally located in the basin area. It has four motels, one bank, and a library. It has two manufacturing plants which employ a total of 182 people. It also has a central water supply, garbage service, and a sanitary sewer system.

Van Buren, headquarters of the Ozark National Scenic Riverways, had a population of 714 in 1970. At that time, there were five motels with a total of 68 units. Their Chamber of Commerce estimates that there were an average of 4,000 tourists a day in the summer of 1971 (Williams, 1972). Because there is at present such a discrepancy between tourist needs and available facilities, it is estimated that there will be many more motels constructed in the next few years.

Indicative of this growth in the Van Buren area is the acquisition by the Neil Land Company of 2,300 acres of land north of Van Buren. The company,

which promises to protect the natural, rustic setting, plans to build 30 lakes and sell hundreds of lots. This development, called "Deer Run" is the only new development directly abutting the 140 miles of the Current River and is part of the nationwide Kampground of America (KOA) system.

The company claims that the sites will be well planned and that the environment will be protected. A planner from the Leo A. Daly Co., the architectural firm hired to lay out the acreage, says that "canoeists should be able to float through the 3.2 miles of Deer Run River frontage without ever knowing they're here" (Anonymous, 1972).

The present Deer Run KOA campground has a septic system and drain field and the Neil Land Company plans to have its cottages hooked into a new lagoon.

This development should give tourism around Van Buren a tremendous boost, but the impact of the community and on the environment will have to be studied closely. The Neil Canoe and Boat Company, which maintains facilities at the present KOA Campground, reported a 50 percent increase in rentals in the summer of 1971 over 1970, an indication of future growth patterns (Van Buren brochure).

Gann and Harvey (1969) note that "the source of most of the water available to wells, discharging from springs, and flowing on the surface in the Current River and its tributaries, is precipitation within the Current River Basin". Sufficient water for most needs is available from wells, and the water quality of the wells and springs is similar in most respects.

Eminence, in the heart of the basin, has a state approved water supply with its own water treatment plant.

Eminence, Mountain View, and Van Buren have central sanitary sewer systems and use lagoons for sewage disposal. Salem has a primary treatment plant, but its effluent drains north to the Meramec River. West Plains, on the far periphery of the basin, has a treatment plant whose effluent does not drain into the Current River Basin. Most other towns, villages, and rural areas in the basin use septic tanks and privies as a sewage disposal method.

## Summary

Creation of the Ozark National Scenic Riverways has encouraged the rapid growth of tourism in the Current River Basin. Although the area is sparsely populated now, rapid growth is projected for many towns in the basin and on its periphery. West Plains, Salem, Houston, Van Buren, Mountain View, and Birch Tree, because of their location on major access highways, will probably experience an increase in permanent population and the establishment of tourist facilities, such as motels.

There is good highway access now, and the Missouri State Highway Department is alert to future needs.

Floating the Current and Jacks Fork Rivers, camping, hunting, and fishing are the principal recreational pursuits of visitors to the basin area. Many visitors also take advantage of the facilities at the three state parks in or near the basin: Big Spring, Round Spring, and Alley Spring.

Currently the water supply is adequate to the demand, and water quality is good. Except for Salem and West Plains, which have primary treatment plants, and Eminence, Mountain View, and Van Buren, which use lagoons, sewage disposal in most other towns is handled by septic tanks and privies.

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8. Marnell, Leo F., 1972, personal communication, March 3, Ozark Riverways, National Park Service, Department of Interior, Van Buren, Mo.

9. National Park Service, 1960, "Appendix" to A Proposal, Ozark Rivers National Monument, Int. Dup. D. C. 60-70916, Department of Interior Washington, D. C.

10. Williams, Bill, 1972, personal communication, February 18, Chamber of Commerce, Van Buren, Mo.

# TEXAS COUNTY

POPULATION 18,320 (1970)

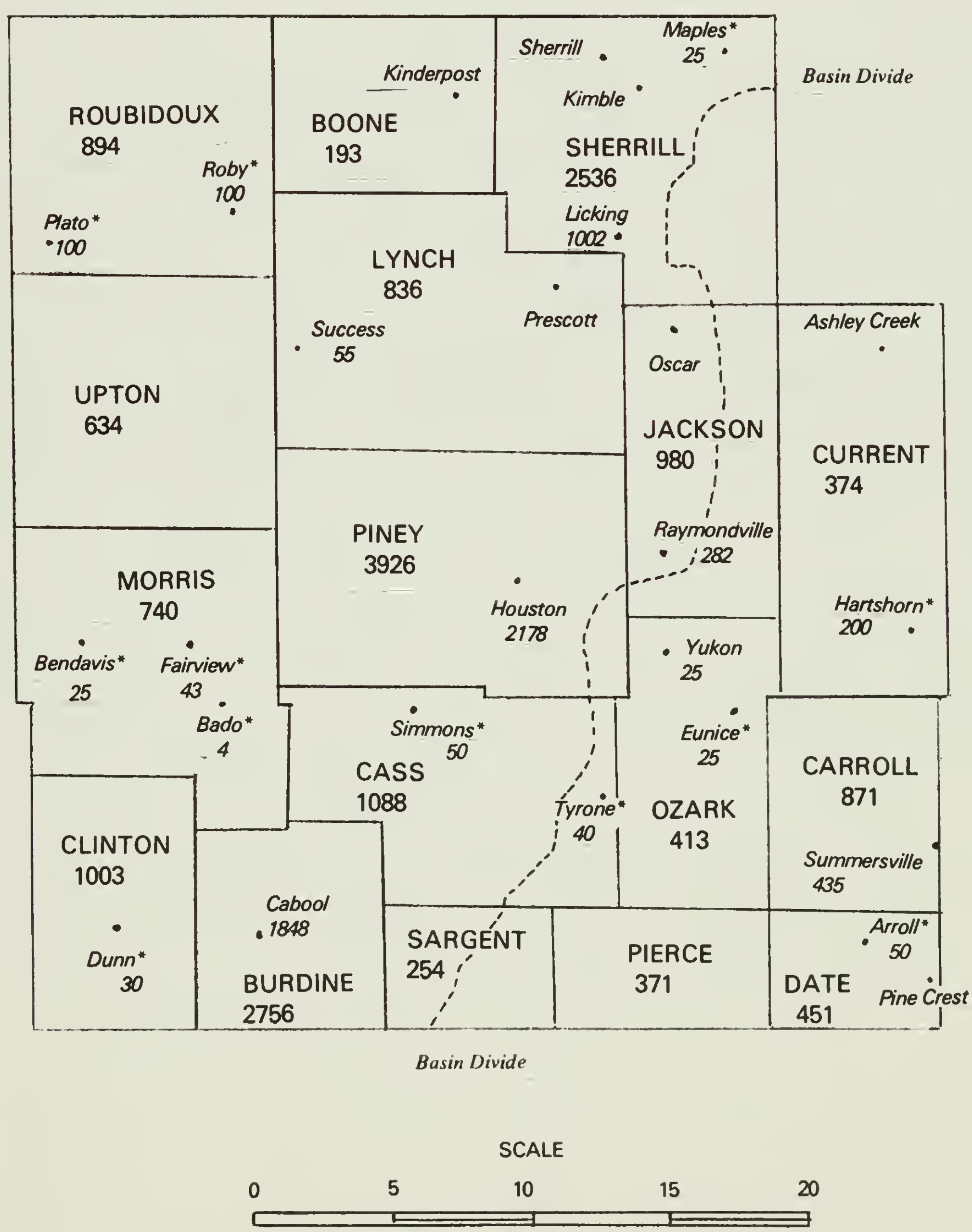



Figure 2-3

# HOWELL COUNTY

POPULATION 23,521 (1970)

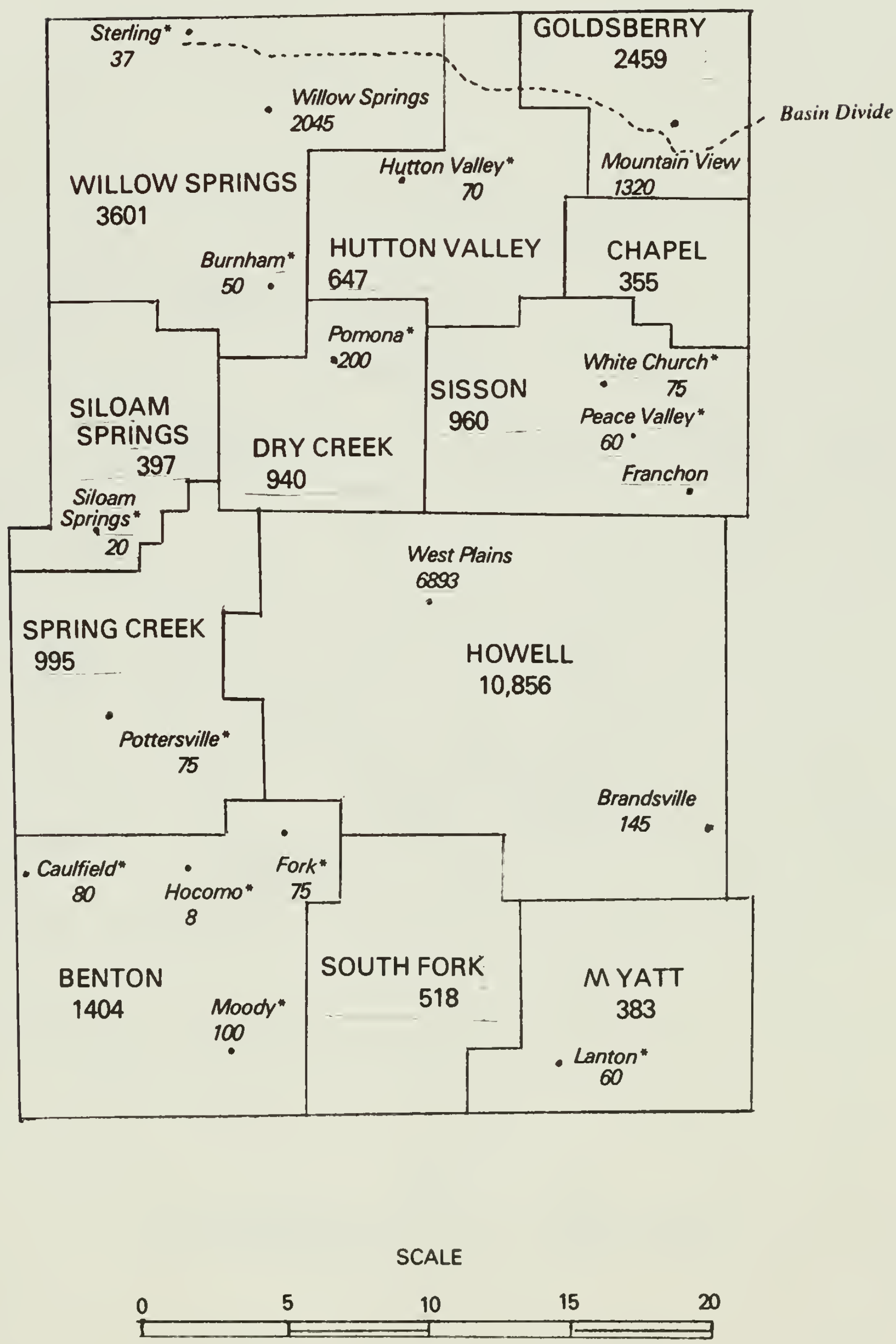



Figure 2-4

# DENT COUNTY

POPULATION 11,457 (1970)

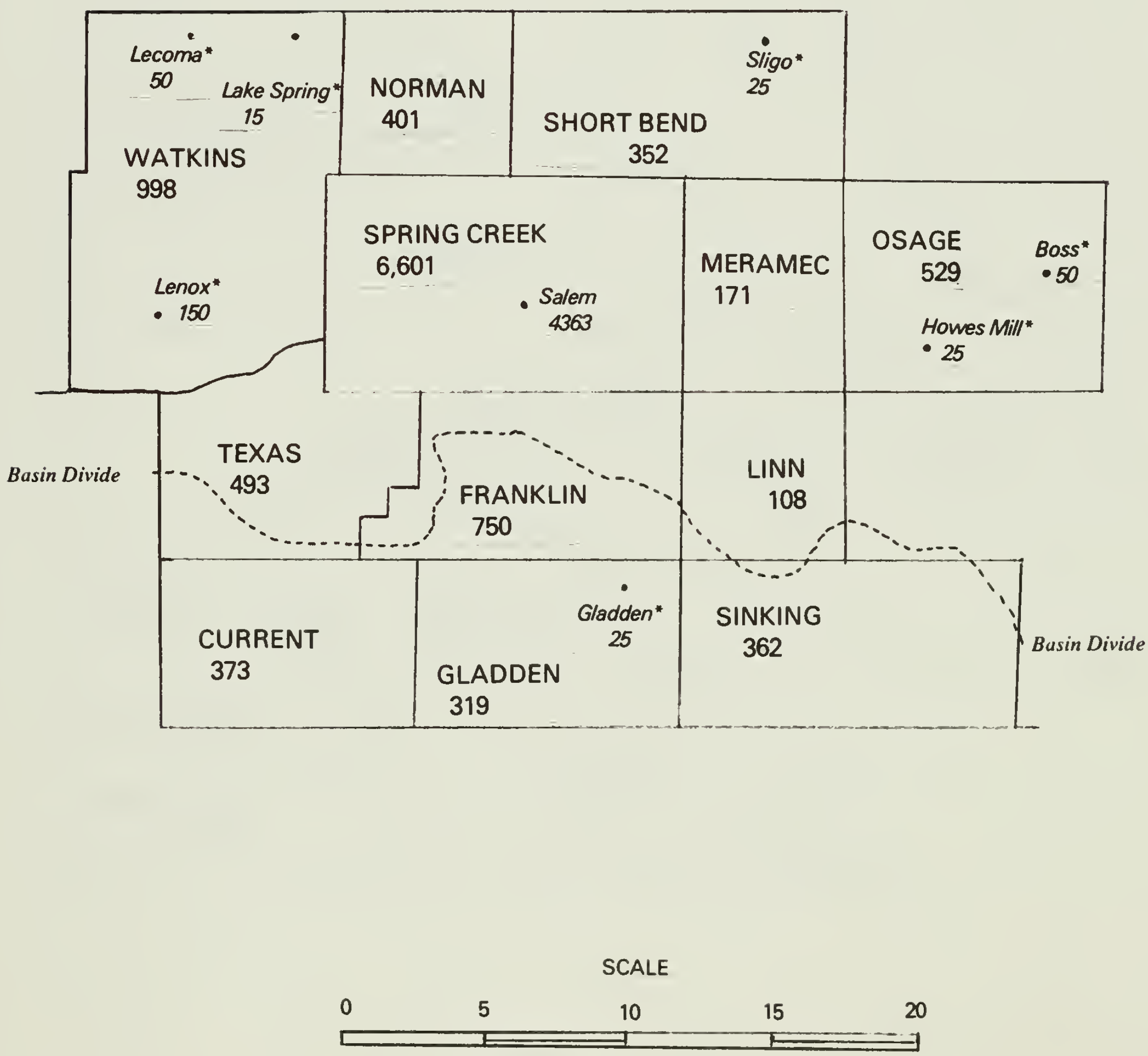



Figure 2-5

# SHANNON COUNTY

POPULATION 7,196 (1970)

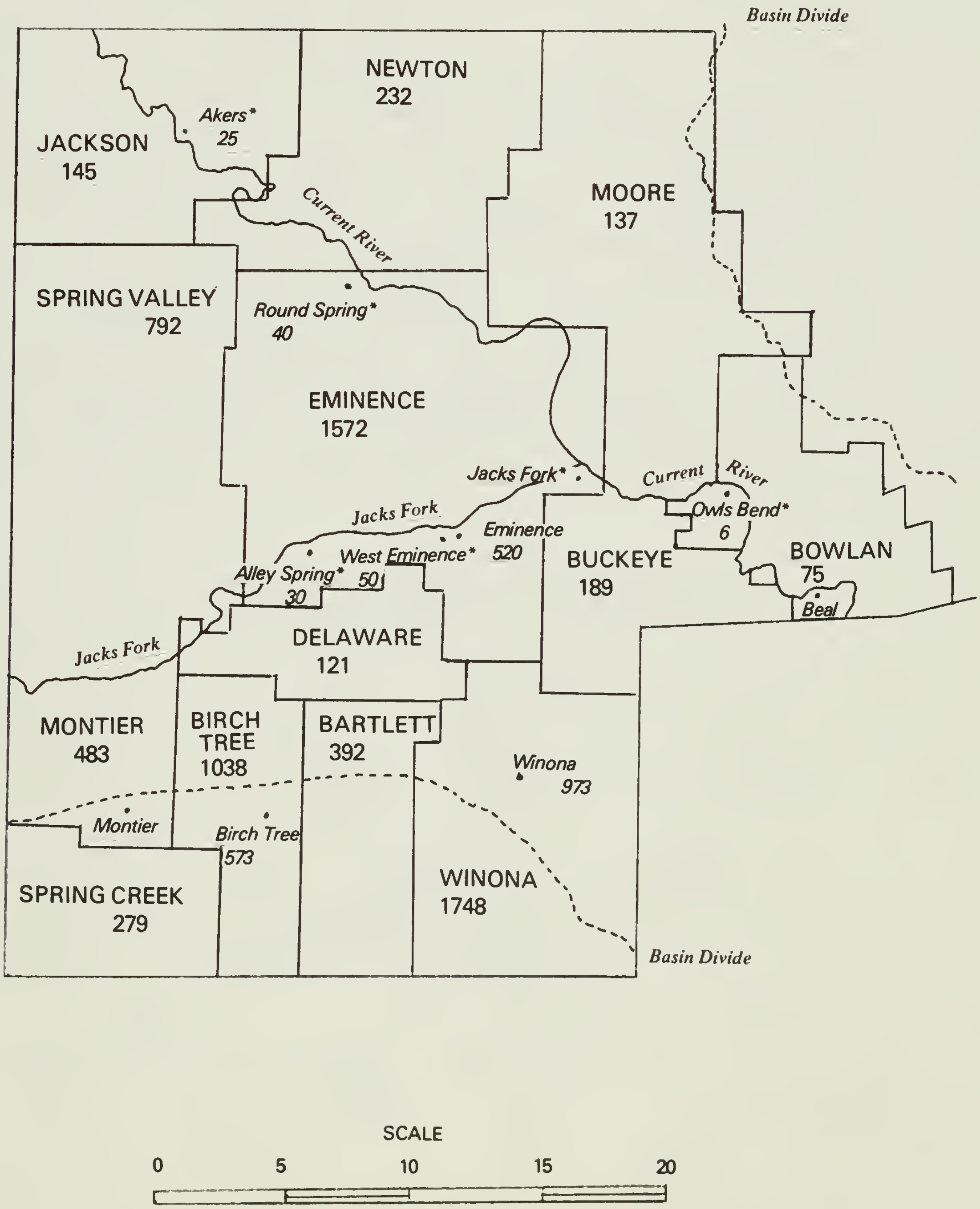
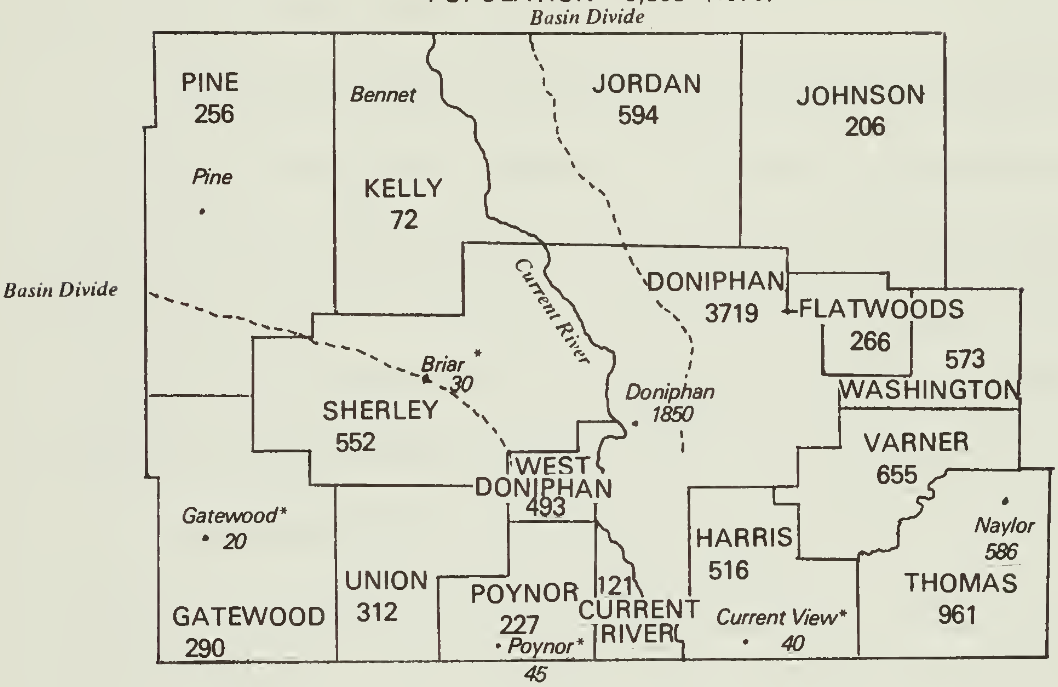



Figure 2-6

# RIPLEY COUNTY

POPULATION 9,803 (1970)




# CARTER COUNTY

POPULATION 3,878 (1970)

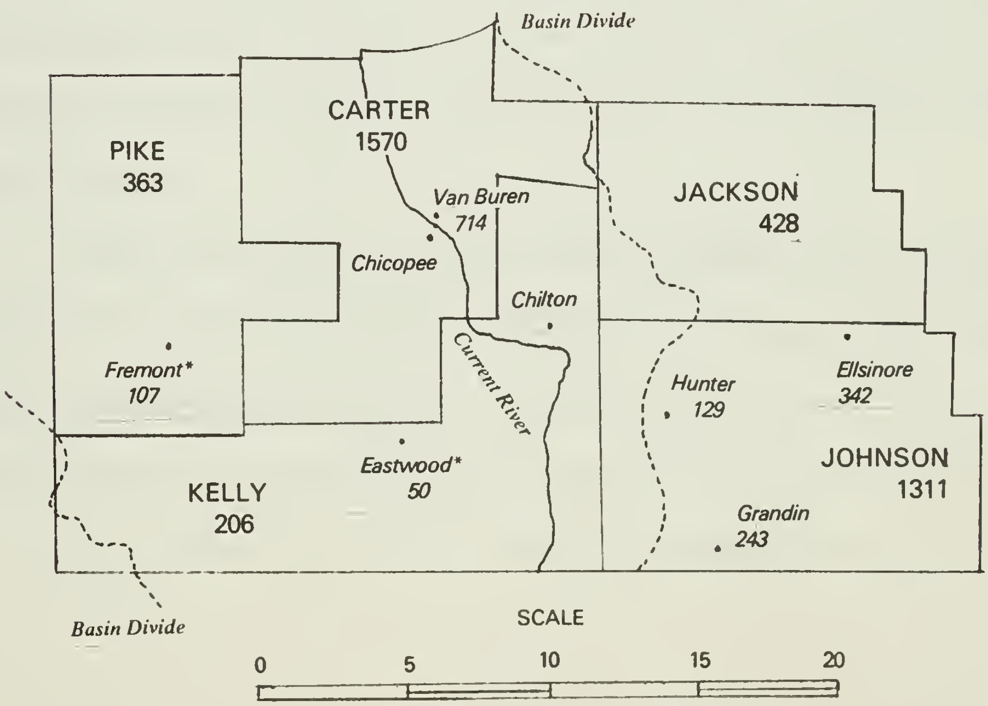



Figure 2-7

# Section III

# HYDROLOGIC DATA

## Published Surface Water Flow Data

Publication of reports presenting surface water flow records of streams in the United States began in 1888 and, with changes in publication format, continues at present. The first series of measurements in the Current River Basin were made on the Current River at Van Buren during the period of October 1912 to June 1921 by the Missouri University Engineering Experiment Station. After June 1921, the series was continued by the U. S. Geological Survey.

The second longest record is from the Current River at Doniphan. Surface flow was measured there from October 1918 to June 1921 by the U. S. Corps of Engineers. Since June 1921, the measurements have been continued by the U. S. Geological Survey.

Since 1921, measurements in the Current River Basin have been taken at 11 continuous record stations, 15 partial record stations (Low Flow) and one Crest-Stage partial record station, a total of 27 stations (see Table 3-1). Stations are listed by name and number in downstream sequence in all water-supply reports.

Until 1966, all station records in the United States were published in a series of U. S. Geological Survey (USGS) water-supply papers entitled Surface Water Supply of the United States. These were subdivided into 14 parts on the basis of natural drainage boundaries. Records for the Current River Basin were published each year in Part 7, Lower Mississippi River Basin, --the

Current River is tributary to the Black River, which is tributary to the White River which flows into the lower Mississippi.

In 1966, the USGS began to publish water supply and surface flow data on a state-boundary basis, rather than by the 14 natural drainage boundaries. Therefore, since that date, Current River Basin measurements have appeared annually in a series of publications titled Water Resources Data for Missouri (Part 1. Surface Water Records). (Distribution of these basic-data reports is limited and primarily for local needs. Records will be published in USGS water-supply papers at five-year intervals.)

To facilitate identification and ensure accuracy, the USGS began, in 1951, to number their stations which until then were only named. "The order of listing used before the publication of the 1951 report listed first all stations on the main stem from the headwaters toward the mouth, then all stations on the uppermost tributary to the main stem from the tributary's source to mouth, and then all stations from source to mouth of the uppermost tributary to the tributary" (USGS Water-Supply Paper 1561, p. 4).

Beginning in 1951, numbers were assigned in a downstream order along the main stem. All stations on a tributary entering above a main-stem station are numbered and listed before that station. In assigning station numbers, no distinction was made between stations having continuous flow records and partial record stations. Gaps were left in the sequence of numbers to allow for new stations that may be established.

The period from 1951 to 1969 was experimental as the station numbering system was being developed. During this time, the Current River stations were identified by a two-part hyphenated eight-digit number. But, the first two digits, 07-, which identified the major drainage basin, were omitted from publication, and the leading and some following zeros were omitted. For example, Current River at Doniphan with a complete number of 07-0680.00, was published as "680." In 1970 a revised numbering scheme of a single eight-digit number was adopted. Under the revised system, Current River at Doniphan is numbered 07068000.

A particularly notable series of USGS Water-Supply Papers, titled Compilation of Records of Surface Waters of the United States Through September 1950 was published in 1955. The purpose of this series was "to make available in summarized form all the surface water records collected up to September 30, 1950." The series included water records from many sources, among them the Corps of Engineers and the University of Missouri recording stations. Data from the Current River Basin is included in Part 7, Water-Supply Paper 1311.

References to all of the published sources of surface water flow data are listed in the following tables. Numbers in the tables refer to USGS water supply papers except where otherwise noted. Table 3-1 lists by name and number all surface flow measurement stations that have been operated in the Current River Basin. Section A lists those that have continuous flow records, Section B those with low-flow partial records, and Section C ones with crest-stage partial records.

TABLE 3-1

U. S. GEOLOGICAL SURVEY SURFACE FLOW STATION NUMBERS AND NAMES

(with abbreviations used in this report)

A. Stations with Continuous Flow Records:

| | | |
|---|---|---|
| 07064300 | Fudge Hollow near Licking, Mo. | FH-LCK |
| 07064400 | Montauk Springs at Montauk, Mo. | MS-MNTK |
| 07064500 | Big Creek near Yukon, Mo. | BCR-YUK |
| 07065000 | Round Spring at Round Spring, Mo. | RS-RS |
| 07065500 | Alley Spring at Alley, Mo. | AS-ALY |
| 07066000 | Jacks Fork at Eminence, Mo. | JF-EMIN |
| 07066500 | Current River near Eminence, Mo. | CR-EMIN |
| 07066800 | Sycamore Creek near Winona, Mo. | SYCR-WIN |
| 07067000 | Current River at Van Buren, Mo. | CR-VB |
| 07067500 | Big Spring near Van Buren, Mo. | BS-VB |
| 07068000 | Current River at Doniphan, Mo. | CR-DON |

B. Stations with Low-Flow Partial Records:

| | | |
|---|---|---|
| 07064480 | Ashley Creek near Montauk State Park, Mo. | ACR-MSP |
| 07064520 | Big Creek at Cedar Grove, Mo. | BCR-CG |
| 07064540 | Gladden Creek at Akers, Mo. | GCR-AK |
| 07064750 | Sinking Creek near Shannondale, Mo. | SCR-SH |
| 07064770 | Barren Creek near Shannondale, Mo. | BACR-SH |
| 07064800 | Sinking Creek near Round Spring, Mo. | SCR-RS |
| 07064950 | Current River at Round Spring, Mo. | CR-RS |
| 07065050 | Big Creek near Round Spring, Mo. | BCR-RS |
| 07065200 | Jacks Fork near Mountain View, Mo. | JF-MV |
| 07065950 | Mahans Creek at West Eminence, Mo. | MCR-WEM |
| 07066100 | Shawnee Creek near Eminence, Mo. | SHCR-EMIN |
| 07066200 | Blair Creek near Round Spring, Mo. | BLCR-RS |
| 07066600 | Rocky Creek near Eminence, Mo. | RCR-EMIN |
| 07066750 | Pine Valley Creek near Van Buren, Mo. | PVCR-VB |
| 07066990 | Pike Creek at Van Buren, Mo. | PCR-VB |

C. Station with Crest-Stage Partial Record:

| | | |
|---|---|---|
| 07066800 | Sycamore Creek near Winona, Mo. | SYCR-WIN |

Table 3-2 lists water-supply papers in which Current River Basin surface water flow records were published to date. It also shows the page references to the 1966-1971 editions of Water Resources Data for Missouri, for those stations for which continuous records are available. This table also lists water-supply papers in which continuous spring flow records were published from 1921 to 1971. From 1921 to 1928, records were kept and published only for Big Spring. Reports for Round Spring and Alley Spring were added in 1929, and Montauk Spring was added in 1965.

Table 3-3 lists by station and water year the water-supply papers containing published partial records of low-flow measurements at additional stations. For one more station, a partial record of crest-stage measurements has been published, as listed in Table 3-4.

Miscellaneous discharge measurements have been made at irregular intervals at many of the springs within the riverways. The springs and water-years for which such measurements are available are listed in Table 3-5 with the USGS water-supply papers in which the measurements are published.

TABLE 3-2

SOURCES OF USGS PUBLISHED STREAMFLOW DATA FOR CONTINUOUS RECORD STATIONS

IN THE CURRENT RIVER BASIN ABOVE DONIPHAN

| Station: | JF-EM 07066000 | CR-EM 07066500 | CR-VB 07067000 | BS-VB 07067500 | CR-DON 07068000 |
|---|---|---|---|---|---|
| Water Year | | | | | |
| 1918-1921 | | | | | 1311 p.111 |
| 1921 | | 8/24-9/30 527 p.13 | 6/18-9/30 527 p.14 | 1/8-6/30 547 p.42 | 6/14-9/30 527 p.15 |
| 1922 | 10/18-9/30 547 p.40 | 547 p.34 | 547 p.36 | 547 p.42 | 547 p.38 |
| 1923 | 567 p.40 | 567 p.36 | 567 p.37 | 4/1-9/30 567 p.42 | 567 p.39 |
| 1924 | 587 p.45 | 587 p.40 | 587 p.41 | 587 p.47 | 587 p.43 |
| 1925 | 607 p.42 | 607 p.35 | 607 p.39 | 607 p.43 | 607 p.40 |
| 1926 | 627 p.41 | 627 p.37 | 627 p.38 | 627 p.43 | 627 p.40 |
| 1927 | 247 p.38 | 732 p.57 | 647 p.35 | 647 p.39 | 647 p.36 |
| 1928 | 732 p.65 | 732 p.57 | 667 p.35 | 667 p.37 | 667 p.36 |
| 1929 | 732 p.65 | 732 p.57 | 687 p.38 | 687 p.40 | 687 p.39 |
| 1930 | 732 p.65 | 732 p.57 | 702 p.55 | 702 p.59 | 702 p.56 |
| 1931 | 732 p.65 | 732 p.57 | 717 p.50 | 717 p.55 | 717 p.51 |
| 1932 | 732 p.65 | 732 p.57 | 732 p.62 | 732 p.70 | 732 p.63 |
| 1933 | 747 p.60 | 747 p.56 | 747 p.57 | 747 p.62 | 747 p.58 |
| 1934 | 762 p.58 | 762 p.54 | 762 p.55 | 762 p.60 | 762 p.56 |
| 1935 | 787 p.63 | 787 p.59 | 787 p.60 | 787 p.66 | 787 p.61 |
| 1936 | 807 p.63 | 807 p.59 | 807 p.60 | 807 p.65 | 807 p.61 |
| 1937 | 827 p.60 | 827 p.56 | 827 p.57 | 827 p.62 | 827 p.58 |
| 1938 | 857 p.67 | 857 p.63 | 877 p.79 | 857 p.69 | 857 p.65 |
| 1939 | 877 p.83 | 877 p.78 | 897 p.79 | 877 p.85 | 877 p.81 |

Vol. No. source listings refer to USGS Water-Supply Papers, except where otherwise noted.

Date listings refer to records for less than one full water year.

TABLE 3-2 (continued)

| Station: | JF-EM 07066000 | CR-EM 07066500 | CR-VB 07067000 | BS-VB 07067500 | CR-DON 07068000 |
|---|---|---|---|---|---|
| Water Year | | | | | |
| 1940 | 897 p.82 | 897 p.78 | 897 p.79 | 897 p.83 | 897 p.81 |
| 1941 | 927 p.77 | 927 p.74 | 927 p.75 | 927 p.78 | 927 p.76 |
| 1942 | 957 p.81 | 957 p.78 | 957 p.79 | 957 p.82 | 957 p.80 |
| 1943 | 977 p.81 | 977 p.78 | 977 p.79 | 977 p.82 | 977 p.80 |
| 1944 | 1007 p.83 | 1007 p.80 | 1007 p.81 | 1007 p.84 | 1007 p.82 |
| 1945 | 1037 p.85 | 1037 p.82 | 1037 p.83 | 1037 p.86 | 1037 p.84 |
| 1946 | 1057 p.84 | 1057 p.81 | 1057 p.82 | 1057 p.85 | 1057 p.83 |
| 1947 | 1087 p.86 | 1087 p.83 | 1087 p.84 | 1087 p.87 | 1087 p.85 |
| 1948 | 1117 p.89 | 1117 p.86 | 1117 p.87 | 1117 p.90 | 1117 p.88 |
| 1949 | 1147 p.92 | 1147 p.88 | 1147 p.89 | 1147 p.93 | 1147 p.90 |
| 1950 | 1177 p.93 | 1177 p.89 | 1177 p.90 | 1177 p.94 | 1177 p.91 |
| 1951 | 1211 p.86 | 1211 p.87 | 1211 p.88 | 1211 p.89 | 1211 p.90 |
| 1952 | 1241 p.89 | 1241 p.90 | 1241 p.91 | 1241 p.92 | 1241 p.93 |
| 1953 | 1281 p.90 | 1281 p.91 | 1281 p.92 | 1281 p.93 | 1281 p.94 |
| 1954 | 1341 p.85 | 1341 p.86 | 1341 p.87 | 1341 p.88 | 1341 p.89 |
| 1955 | 1391 p.89 | 1391 p.90 | 1391 p.91 | 1391 p.92 | 1391 p.93 |
| 1956 | 1441 p.91 | 1441 p.92 | 1441 p.93 | 1441 p.94 | 1441. p.95 |
| 1957 | 1511 p.94 | 1511 p.95 | 1511 p.96 | 1511 p.97 | 1511 p.98 |
| 1958 | 1561 p.91 | 1561 p.92 | 1561 p.93 | 1561 p.94 | 1561 p.95 |
| 1959 | 1631 p.89 | 1631 p.90 | 1631 p.91 | 1631 p.92 | 1631 p.93 |
| 1960 | 1711 p.86 | 1711 p.87 | 1711 p.88 | 1711 p.89 | 1711 p.90 |
| 1961 | 1920 p.231 | 1920 p.234 | 1920 p.237 | 1920 p.240 | 1920 p.243 |

Vol. No. source listings refer to USGS Water-Supply Papers, except where otherwise noted.

TABLE 3-2 (continued)

| Station: | JF-EM 07066000 | CR-EM 07066500 | CR-VB 07067000 | BS-VB 07067500 | CR-DON 07068000 |
|---|---|---|---|---|---|
| Water Year | | | | | |
| 1962 | 1920 p.231 | 1920 p.234 | 1920 p.237 | 1920 p.240 | 1920 p.243 |
| 1963 | 1920 p.231 | 1920 p.234 | 1920 p.237 | 1920 p.240 | 1920 p.243 |
| 1964 | 1920 p.231 | 1920 p.234 | 1920 p.237 | 1920 p.240 | 1920 p.243 |
| 1965 | 1920 p.231 | 1920 p.234 | 1920 p.237 | 1920 p.240 | 1920 p.243 |
| 1966[1] | p.142 | p.143 | p.144 | p.145 | p.146 |
| 1967[2] | p.150 | p.151 | p.152 | p.153 | p.154 |
| 1968[3] | p.161 | p.162 | p.163 | p.164 | p.165 |
| 1969[4] | p.165 | p.166 | p.167 | p.168 | p.169 |
| 1970[5] | p.288 | p.289 | p.290 | p.291 | p.292 |
| 1971[6] | p.176 | p.177 | p.178 | p.179 | p.180 |

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Vol. No. source listings refer to USGS Water-Supply Papers, except where otherwise noted.

Other sources: 1. Water Resources Data for Missouri, Part 1, 1966
2. " " " " " " " 1967
3. " " " " " " " 1968
4. " " " " " " " 1969
5. " " " " " " " 1970
6. " " " " " " " 1971

TABLE 3-2 (continued)

| Station: | FH-LCK 07064300 | MS-MNTK 07064400 | BC-YUK 07064500 | RS-RS 07065000 | AS-ALY 07065500 |
|---|---|---|---|---|---|
| Water Year | | | | | |
| 1929 | | | | 702 p. 57 | 717 p. 53 |
| 1930 | | | | 702 p. 57 | 717 p. 53 |
| 1931 | | | | 717 p. 52 | 717 p. 53 |
| 1932 | | | | 732 p. 64 | 732 p. 69 |
| 1933 | | | | 747 p. 59 | 747 p. 61 |
| 1934 | | | | 762 p. 57 | 762 p. 59 |
| 1935 | | | | 787 p. 65 | 787 p. 65 |
| 1936 | | | | 807 p. 62 | 807 p. 64 |
| 1937 | | | | 827 p. 59 | 827 p. 61 |
| 1938 | | | | 857 p. 66 | 857 p. 68 |
| 1939 | | | | 877 p. 82 | 877 p. 84 |
| 1940-1941 | | | | See Table 3-5 | |
| 1949 | | | 6/1-9/30 1147 p. 91 | | |
| 1950 | | | 1177 p. 92 | | |
| 1951 | | | 1211 p. 85 | | |
| 1952 | | | 1241 p. 88 | | |
| 1953 | | | 1281 p. 89 | | |
| 1954 | | | 1341 p. 84 | | |
| 1955 | | | 1391 p. 88 | | |
| 1956 | | | 1441 p. 90 | | |
| 1957 | p.275[5] | | 1511 p. 93 | | |

Vol. No. source listings refer to USGS Water-Supply Papers, except where otherwise noted. (See end of Table.)

Date listings refer to records for less than one full water year.

TABLE 3-2 (continued)

| Station: | FH-LCK 07064300 | MS-MNTK 07064400 | BC-YUK 07064500 | RS-RS 07065000 | AS-ALY 07065500 |
|---|---|---|---|---|---|
| Water Year | | | | | |
| 1958 | p. 276[5] | | 1561 p. 90 | | |
| 1959 | p. 276[5] | | 1631 p. 88 | | |
| 1960 | p. 277[5] | | 1711 p. 85 | | |
| 1961 | p. 277[5] | | 1920 p.228 | | |
| 1962 | p. 278[5] | | 1920 p.228 | | |
| 1963 | p. 278[5] | | 1920 p.228 | | |
| 1964 | p. 279[5] | | 1920 p.228 | | |
| 1965 | p. 279[5] | p. 155[3] | 1920 p.228 | | |
| 1966 | p. 280[5] | | | p. 157[3] | |
| 1967 | p. 280[5] | p. 155[3] | | p. 158[3] | |
| 1968 | p. 281[5] | p. 155[3] | | p. 158[3] | |
| 1969 | p. 281[5] | | | p. 163[4] | |
| 1970 | p. 282[5] | | | p. 286[5] | |
| 1971 | p. 172[6] | | | p. 174[6] | |

Vol. No. source listings refer to USGS Water-Supply Papers, except where otherwise noted.

Other sources: 1. Water Resources Data for Missouri, Part 1, 1966
2. " " " " " " " 1967
3. " " " " " " " 1968
4. " " " " " " " 1969
5. " " " " " " " 1970
6. " " " " " " " 1971

TABLE 3-3

SOURCES OF USGS PUBLISHED RECORDS FOR LOW-FLOW PARTIAL RECORD STATIONS

| Station | Water Year | Source |
|---|---|---|
| Ashley Creek nr. Montauk S.P. (07064480) | 1971 | WRDM 1971, p. 203 |
| Big Creek at Cedar Grove (07064520) | 1971 | " 1971, p. 203 |
| Gladden Creek at Akers (07064540) | 1971 | " 1971, p. 203 |
| Sinking Creek nr. Shannondale (07064750) | 1969-1971 | " 1971, p. 203 |
| Barren Creek nr. Shannondale (07064770) | 1969-1971 | " 1971, p. 203 |
| Sinking Creek nr. Round Spring (07064800) | 1942 | WSP 957, p. 396 |
| | 1943 | " 977, p. 374 |
| | 1945 | " 1037, p. 407 |
| | 1947 | " 1087, p. 408 |
| | 1952 | " 1241, p. 501 |
| | 1961-1965 | " 1920, p.1037 |
| | 1966 | WRDM 1966, p. 158 |
| | 1967 | " 1967, p. 174 |
| | 1968 | " 1971, p. 203 |
| | 1971 | " 1971, p. 203 |
| Current River at Round Spring (07064950) | 1942 | WSP 957, p. 396 |
| | 1943 | " 977, p. 374 |
| | 1945 | " 1037, p. 401 |
| | 1946 | " 1047, p. 407 |
| | 1947 | " 1087, p. 408 |
| | 1961-1965 | " 1920, p.1038 |
| | 1966 | WRDM 1966, p. 158 |
| | 1967 | " 1967, p. 174 |

WSP refers to USGS Water-Supply Papers

WRDM refers to Water Resources Data for Missouri

TABLE 3-3 (continued)

| Station | Water Year | Source |
| --- | --- | --- |
| Big Creek nr. Round Spring (07065050) | 1969-1971 | WRDM 1971, p. 203 |
| Jacks Fork nr. Mountain View (07065200) | 1942 | WSP 957, p. 396 |
| | 1943 | " 977, p. 375 |
| | 1945 | " 1037, p. 401 |
| | 1946 | " 1057, p. 407 |
| | 1952 | " 1241, p. 501 |
| | 1961-1965 | " 1920, p.1038 |
| | 1966 | WRDM 1966, p. 158 |
| | 1967 | " 1967, p. 174 |
| Mahans Creek at W. Eminence (07065950) | 1969-1971 | WRDM 1971, p. 203 |
| Shawnee Creek nr. Eminence (07066100) | 1971 | WRDM 1971, p. 203 |
| Blair Creek nr. Round Spring (07066200) | 1969-1971 | WRDM 1971, p. 203 |
| Rocky Creek nr. Eminence (07066600) | 1969-1971 | WRDM 1971, p. 203 |
| Pine Valley Creek nr. Van Buren (07066750) | 1971 | WRDM 1971, p. 203 |
| Pike Creek at Van Buren (07066990) | 1969-1971 | WRDM 1971, p. 203 |

WSP refers to USGS Water-Supply Papers

WRDM refers to Water Resources Data for Missouri

TABLE 3-4

USGS PUBLISHED RECORDS FOR CREST-STAGE PARTIAL-RECORD STATION

| Station | Water Year | Source |
|---|---|---|
| Sycamore Creek nr. Winona (07066800) | 1955-1958 | WSP 1561 p. 522 |
| | 1959 | " 1631 p. 536 |
| | 1960 | " 1711 p. 564 |
| | 1961-1965 | " 1920 p.1075 |
| | 1966 | WRDM 1966 p. 167 |
| | 1967 | " 1967 p. 184 |
| | 1968 | " 1970 p. 184 |
| | 1969 | " 1970 p. 186 |
| | 1970 | " 1970 p. 324 |
| | 1971 | " 1971 p. 212 |

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WSP refers to USGS Water-Supply Papers

WRDM refers to Water Resources Data for Missouri

# TABLE 3-5

## SOURCES OF USGS MISCELLANEOUS SPRING DISCHARGE MEASUREMENTS

| Spring | Water Year | Source |
|---|---|---|
| Montauk Springs nr. Montauk (07064400) | | |
| | 1924 | WSP 587 p. 120 |
| | 1933 | " 747 p. 116 |
| | 1934 | " 762 p. 125 |
| | 1936 | " 807 p. 145 |
| | 1942 | " 957 p. 396 |
| | 1956 | " 1441 p. 474 |
| | 1964-1965 | " 1920 p.1096 |
| | 1967 | WRDM 1967 p. 187 |
| | 1968 | " 1968 p. 155 |
| | 1969 | " 1969 p. 188 |
| | 1970 | " 1970 p. 326 |
| | 1971 | " 1971 p. 214 |
| Welch Spring nr. Akers | | |
| | 1924 | WSP 587 p. 120 |
| | 1933 | " 747 p. 116 |
| | 1936 | " 807 p. 145 |
| | 1942 | " 957 p. |
| | 1953 | " 1281 p. 494 |
| | 1967 | WRDM 1967 p. 187 |
| | 1968 | " 1968 p. 186 |
| | 1969 | " 1971 p. 189 |
| | 1971 | " 1971 p. 215 |
| Cave Spring nr. Cedar Grove (now nr. Akers) | | |
| | 1924 | WSP 587 p. 120 |
| | 1940 | " 897 p. 343 |
| Pulltite Spring nr. Round Spring | | |
| | 1924 | WSP 587 p. 120 |
| | 1933 | " 747 p. 116 |
| | 1969 | WRDM 1969 p. 189 |
| | 1970 | " 1970 p. 326 |
| | 1971 | " 1971 p. 215 |
| Highley Spring nr. Bunker | | |
| | 1933 | WSP 747 p. 116 |
| | 1936 | " 807 p. 145 |
| | 1969 | WRDM 1929 p. 189 |
| Twin Spring nr. Round Spring | | |
| | 1969 | WRDM 1969 p. 189 |
| Round Spring at Round Spring (07065000) | | |
| | 1923 | WSP 567 p. 96 |
| | 1924 | " 587 p. 120 |
| | 1925 | " 607 p. 109 |
| | 1929-1939 | See Table 3 - 2 |
| | 1948 | WSP 1117 p. 409 |
| | 1954 | " 1341 |
| | 1956 | " 1441 p. 474 |
| | 1964-1965 | " 1920 p.1096 |
| | 1966 | WRDM 1966 p. 172 |
| | 1967 | " 1967 p. 187 |
| Ebb and Flow Spring nr. Eminence | | |
| | 1943 | WSP 977 p. 375 |
| Clear Spring nr. Van Buren | | |
| | 1943 | WSP 977 p. 375 |
| McCubben Spring nr. Mountain View | | |
| | 1927 | WSP 647 p. 95 |
| | 1933 | " 747 p. 117 |
| | 1936 | " 807 p. 145 |
| Jacks Fork Spring nr. Mountain View | | |
| | 1936 | WSP 807 p. 145 |
| Blue Spring nr. Mountain View | | |
| | 1936 | WSP 807 p. 145 |
| Rymer (Ebb and Flow) Spring nr. Birch Tree | | |
| | 1936 | WSP 807 p. 145 |
| | 1939 | " 807 p. 345 |

WSP refers to USGS Water-Supply Papers

WRDM refers to Water Resources Data for Missouri

TABLE 3-5 (continued)

| Spring | Water Year | Source |
|---|---|---|
| Alley Spring nr. Alley (07065500) | | |
| | 1922 | WSP 547 p. 103 |
| | 1925 | " 607 p. 109 |
| | 1929-1939 | See Table 3 - 2 |
| | 1941 | " 927 p. 348 |
| | 1948 | " 1117 p. 409 |
| | 1954 | " 1341 p. 469 |
| | 1955 | " 1391 p. 458 |
| | 1964-1965 | " 1920 p.1096 |
| | 1966 | WRDM 1966 p. 172 |
| | 1967 | " 1967 p. 187 |
| Gang Spring nr. Eminence | | |
| | 1943 | WSP 977 p. 375 |
| Cove (Cave) Spring nr. Eminence | | |
| | 1943 | WSP 977 p. 375 |
| Powder Mill Spring nr. Eminence | | |
| | 1941 | WSP 927 p. 348 |
| | 1943 | " 977 p. 375 |
| | 1968 | WRDM 1968 p. 186 |
| Blue Spring nr. Eminence (07066550) | | |
| | 1923 | WSP 567 p. 96 |
| | 1924 | " 587 p. 120 |
| | 1925 | " 607 p. 109 |
| | 1933 | " 747 p. 117 |
| | 1941 | " 927 p. 348 |
| | 1942 | " 957 p. |
| | 1965 | " 1920 p.1096 |
| | 1971 | WRDM 1971 p. 215 |
| Gravel Spring nr. Van Buren | | |
| | 1936 | WSP 807 p. 145 |
| Dazey Spring nr. Van Buren | | |
| | 1943 | WSP 977 p. 375 |
| Clear Spring nr. Van Buren | | |
| | 1943 | WSP 977 p. 375 |
| Mill Creek nr. Van Buren | | |
| | 1943 | WSP 977 p. 375 |
| Cement Spring nr. Hunter | | |
| | 1954 | WSP 1341 p. 469 |
| Cave Spring nr. Chilton | | |
| | 1954 | WSP 1341 p. 469 |
| Tile Spring nr. Hunter | | |
| | 1954 | WSP 1341 p. 469 |
| Jordan Spring nr. Hunter | | |
| | 1934 | WSP 762 p. 125 |
| | 1936 | " 807 p. 145 |
| Cave Spring nr. Hunter | | |
| | 1934 | WSP 762 p. 125 |
| | 1936 | " 807 p. 145 |
| | 1969 | WRDM 1969 p. 189 |
| Panther Spring nr. Hunter | | |
| | 1946 | WSP 1057 p. 407 |
| Cedar Spring nr. Grandin | | |
| | 1946 | WSP 1057 p. 407 |
| Phillips Spring nr. Van Buren | | |
| | 1925 | WSP 607 p. 109 |
| | 1936 | " 807 p. 145 |
| | 1946 | " 1057 p. 407 |
| | 1968 | WRDM 1968 p. 186 |
| Spring Hollow Spring nr. Grandin | | |
| | 1946 | WSP 1057 p. 407 |
| Jakes Valley Spring nr. Doniphan | | |
| | 1946 | WSP 1057 p. 407 |
| Sandboil Spring nr. Doniphan | | |
| | 1946 | WSP 1057 p. 407 |

WSP refers to USGS Water-Supply Papers

WRDM refers to Water Resources Data for Missouri

III - B Published Water Quality Data

The earliest measurements of water quality in the Current River Basin were made by the Missouri Geological Survey in 1925 when chemical analyses were made of water from six river stations from Crooked Creek near Montauk to Current River at Doniphan and from eight springs. The results were published by the Missouri Geological Survey in an undated pamphlet in late 1926 or 1927. The same data for the springs were republished in The Large Springs of Missouri (Beckman and Hinchey, 1944). New analyses of water from the same springs were made in 1952. These, and the results of the 1925 study, are published in Springs of Missouri (Vineyard and Feder, 1974, p. 74-77).

Publication of measurements of water quality, including temperature, chemical quality, and suspended sediments was begun elsewhere by the USGS in 1941. In the Current River Basin, the first continuous water quality measurements were water temperature measurements of the Current River at Doniphan starting in March, 1965. Chemical analyses of water from several springs and from the Current River at Doniphan were completed and published in 1969. These analyses have been continued twice each year (spring and late summer or early fall) to the present. Measurements of total coliform, fecal coliform, and fecal streptococcal bacteria were added to the chemical analyses beginning in 1971 and continuing to date.

The eight stations in the Current River Basin at which water quality is presently measured are listed by number and name (in downstream order)

in Table 3-6. Welch Spring near Akers, Missouri, and Pulltite Spring (spelled "Pulltight" in some publications) near Round Spring have not, to date, been assigned numbers by the USGS. Table 3-7 lists references for water quality data, by water year, for these stations.

TABLE 3-6

SOURCES OF USGS PUBLISHED WATER QUALITY STATION NUMBERS AND NAMES

(with abbreviations used in this report)

| | | |
|---|---|---|
| 07064400 | Montauk Springs at Montauk, Mo. | MS-MNTK |
| --- | Welch Spring near Akers, Mo. | WS-AK |
| --- | Pulltite Spring near Round Spring, Mo. | PS-RS |
| 07065000 | Round Spring at Round Spring, Mo. | RS-RS |
| 07065500 | Alley Spring At Alley, Mo. | AS-ALY |
| 07066550 | Blue Spring near Eminence, Mo. | BLS-EM |
| 07067500 | Big Spring near Van Buren, Mo. | BS-VB |
| 07068000 | Current River at Doniphan, Mo. | CR-DON |

TABLE 3-7

SOURCES OF USGS PUBLISHED WATER-SUPPLY PAPERS, WATER QUALITY DATA,

IN THE CURRENT RIVER BASIN ABOVE DONIPHAN

| Water Year | MS-MNTK 07064400 | WS-AK | PS-RS | RS-RS 07065000 |
|---|---|---|---|---|
| 1925, 1952 [1] 1964-1966 | p. 76- 77 | p. 76- 77 | p. 76- 77 | p. 76- 77 |
| 1967[2] | p.290-291 | p.292-293 | ——— | p.292-293 |
| 1968[2] | p.290-294 | p.292-293 | ——— | p.292-293 |
| 1969[3] | p.310-311 | p.310-311 | p.310-311 | p.310-311 |
| 1970[4] | p.476-477 | ——— | p.476-477 | p.476-477 |
| 1971[5] | p.370-371 | p.370-371 | p.370-371 | p.370-371 |

| Water Year | AS-ALY 07065500 | POWDER MILL | BLS-EM 07066550 | BS-VB 07067500 | CR-DON 07068000 |
|---|---|---|---|---|---|
| 1914, 1941 [1] 1963-1966 | p. 74- 75 | ——— | p. 74- 75 | p. 74- 75 | WSP 1964 p.50 |
| 1966 | ——— | ——— | ——— | ——— | " 1994 p.49 |
| 1967[2] | p.292-293 | p.292-293 | ——— | p.292-293 | " 2014 p.56 |
| 1968[2] | p.292-293 | ——— | ——— | p.292-293 | p.254 |
| 1969[3] | p.310-311 | ——— | p.310-311 | p.312-313 | p.261, 304-307 |
| 1970[4] | p.476-477 | ——— | p.476-477 | p.476-477 | p.426-427 |
| 1971[5] | p.370-371 | ——— | p.370-371 | p.370-371 | p.324-325 |

WSP refers to USGS Water-Supply Papers

Other Sources:
1. Springs of Missouri, 1974.
2. Water Resources Data for Missouri, Part 2, 1968
3. " " " " " " " 1969
4. " " " " " " " 1970
5. " " " " " " " 1971

# Section IV

## PRECIPITATION-DISCHARGE STUDY ON THE CURRENT RIVER

Susan Blickensderfer

The precipitation-discharge part of this study was undertaken to acquire a better understanding of the relationship of river flow to rainfall. There were two objectives:

1. To find the relationship between monthly precipitation and monthly runoff for each individual month of the ten year period studies (January 1961 to December 1970). This relationship was then to be used to calculate the monthly discharge from various subbasins which do not have gaged discharge measurements.
2. To find a general relationship between monthly rainfall and monthly discharge. This attempt was not completely successful, and will require further study.

General background information, such as site description, time period and subbasin divisions used, precedes the major objectives-results portion of this section. A preliminary study on the calculation of monthly rainfall data is also part of the introductory section which facilitates understanding of the material that follows.

This original study was done at no expense to National Park Service, Department of Interior. It is included here for its particular relevance to the Current River Basin.

## Site Description

The area studied was the Current River drainage basin above Doniphan, Missouri. This area was divided into six subbasins: Upper Current, Spring Valley, Middle Current, Jacks Fork, Owls Bend, and Lower Current, as shown in Figure 1. In addition, several of these subbasins were grouped together to form the Current River-Eminence and Current River-Van Buren subbasins. The entire drainage area was called Current River-Doniphan. The Jacks Fork-Eminence, Current River-Eminence, Current River-Van Buren, and Current River-Doniphan basins have discharge gages at their mouths.

This is an area of karst topography. The area is underlain by Roubidoux Sandstone and Gasconade Dolomite of Ordovician age. Many large springs, including Big Spring (claimed to be the largest single orifice spring in the United States), are important tourist attractions. These springs supply the Current River with a large base flow throughout the year. Sinkholes, sinking streams, and cave systems are common.. Because of the large amount of subterranean flow, a water budget method of analysis would be very difficult and could lead to poor results.

The land is deeply dissected by streams, although Spring Valley subbasin has much less relief than the surrounding area. The basin has a continental climate. The average annual precipitation is 45 inches. Almost all of the watershed is forest or pasture land, and the region is sparsely settled.

## Time Period

The month was chosen as the data time period for this study. Two other time periods often used by investigators are the individual storms

CURRENT RIVER DRAINAGE BASIN


Figure 4-1

of a day or two in length, and the entire year. The use of individual storms shows dramatically the relation of rainfall and runoff for a short time period with most variables which affect runoff (temperature, soil moisture, etc.) remaining constant and thus introducing no changes during the time period. The method of yearly averages results in very general relationships including broad ranges in the variables. The month retains characteristics of both of these methods. It is short enough to exclude extreme changes in variables, and yet it will still provide general relationships covering a reasonably long time period.

Subbasin Division

The Current River drainage basin above Doniphan was divided into six subbasins. This allowed the calculated average precipitation over each of the small subbasins to be used in analysis of rainfall and related phenomena, rather than using more general average precipitation values of the entire area. In effect, the smaller the units used, the closer the results will approach reality. More specifically, subbasin division was advisable for the Current River basin because average yearly rainfall increases from 43 inches in the north to 46 inches in the south. However, further division of the subbasins could not be justified because of the lack of rain gages.

Spring Valley subbasin was set apart first because it has much less relief than the remainder of the area. It includes the drainage basin of Spring Valley creek. The Upper Current subbasin includes all the drainage basin above the mouth of the Spring Valley subbasin. Jacks Fork subbasin is the drainage area of Jacks Fork River above the drainage gage located near Eminence. Note that this subbasin does not border at

any point on the Current River. The Middle Current subbasin includes all the drainage area of Jacks Fork River below the Jacks Fork discharge gage on the Current River near Eminence. The Owls Bend subbasin extends south from the boundary of land drained by the Current River drainage gage at Eminence, to the boundary of the land whose discharge is measured by the gage at Van Buren. The remainder of the drainage basin below this drainage gage is called the Lower Current subbasin.

## Calculation of Monthly Rainfall Data

In order to study the relationship of other phenomena to rainfall, it is necessary to have reliable data on precipitation over the region. The Current River study required average monthly total rainfall data over the various subbasins. Weighted average rainfall values were computed using the Theissen method.

### Rain Gages

Both non-recording and recording gages are present in and near the Current River basin. A comparison of the precipitation data from the two types of gages showed a large difference, often as much as an inch, and in one instance, three inches (Oct. 1970, at Alton stations). There is no known method to relate these two sets of data. Since there are more non-recording gages than recording gages present in the basin, and also because there are more missing records in the recording gage data, the non-recording gage values were chosen to represent the precipitation pattern in the basin. Unfortunately, this eliminated the Eminence re-

cording gage in the middle of the basin. Eleven stations in and near the area were ultimately used in calculating average precipitation. The monthly total rainfall in inches was obtained from the Climatological Data records on file at the U.S. Geological Survey in Rolla. The climate is sufficiently warm so that there is no need to differentiate snow and rainfall. The rain gages used and the corresponding data are found in an Appendix.

## Missing Records

Various precipitation records are missing. As Linsley (1958) suggests, these were filled in by the method used by the U.S. Weather Bureau. If the normal average precipitation at three surrounding stations is within 10% of that for the station with the missing record, the arithmetic mean of these three stations is the estimated precipitation for the missing record. The data which are estimated are indicated on the table of precipitation data in the Appendix. The following stations were used to fill in the missing records:

Bunker -- Salem, Clearwater Dam[1]

Licking -- Salem, Houston[1]

Birch Tree -- Alton, Willow Springs, Van Buren

Summersville -- Birch Tree, Houston, Willow Springs

Van Buren -- Clearwater Dam, Alton, Doniphan

Houston -- Summersville, Licking[1]

[1]Because there was no third station nearby, and because the two stations listed are fairly close to the station in question, only two stations were used.

Theissen Method

The Theissen method usually gives more accurate precipitation averages than does simple arithmetic averaging, according to Linsley (1958). To apply this method, the gaging stations are plotted on a map and lines connecting the stations are drawn. The perpendicular bisectors of these lines form polygons which surround the gaging stations. The area within each polygon is assumed to receive the same rainfall as the station inside the polygon. The area of the basin within each polygon is determined by planimetry, and is expressed as a percentage of the total area. This percentage is the weight given to that gaging station.

Application

The Theissen method was used to calculate the average monthly precipitation for the nine subbasins. The location of subbasins, rain gage stations, and the polygons are shown in Figure 4-2. The map was drawn from the Rolla and Poplar Bluff USGS topographic maps, 1:250,000 series. The areas were determined by a polar planimeter. The subbasins and the accompanying percentages for each polygon (identified by its rain gage) are tabulated in Table 4-1. Weighted monthly precipitation values were calculated for the 120 months from January 1961 to December 1970. These values are tabulated in an Appendix.

Error Estimates

The book Hydrology for Engineers by Linsley and others (1958, p. 32) contains a graph of the average error, in inches of rainfall, which is made in calculating precipitation averages for a specific region. This graph (Figure 4-3) was used to estimate error for the Current River averages.

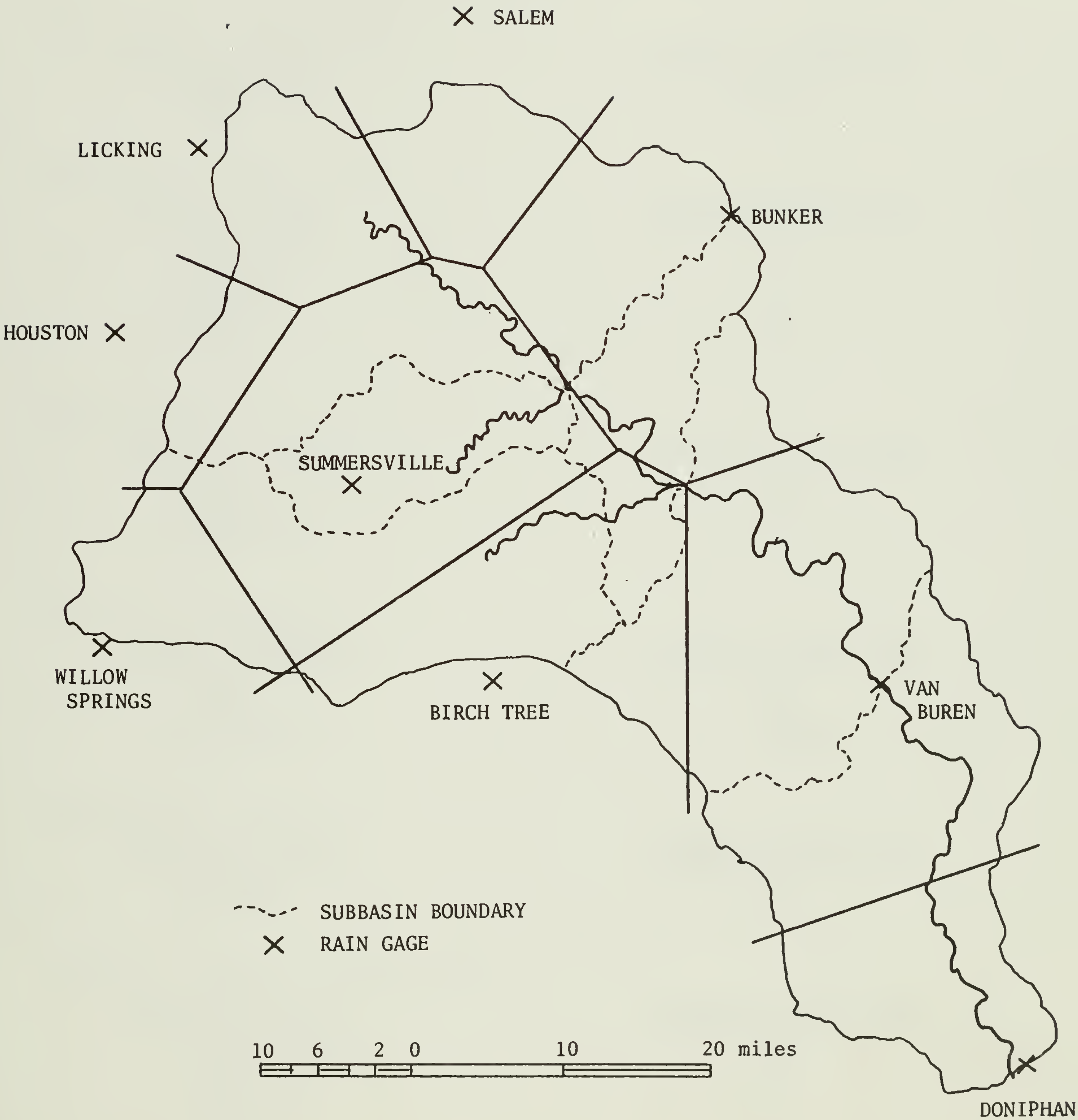

SALEM
LICKING
BUNKER
HOUSTON
SUMMERSVILLE
WILLOW SPRINGS
BIRCH TREE
VAN BUREN
SUBBASIN BOUNDARY
RAIN GAGE
10 6 2 0 10 20 miles
DONIPHAN

Figure 4-2

TABLE 4-1

THEISSEN METHOD AREAS AND WEIGHTS FOR EACH SUBBASIN

Spring Valley (140 sq. mi..)

| Precipitation Gage | Percent of total area |
|---|---|
| Summersville | 100 % |

Upper Current (578 sq. mi.)

| Precipitation Gage | Percent of total area |
|---|---|
| Summersville | 23 % |
| Houston | 9 |
| Licking | 24 |
| Salem | 18 |
| Bunker | 26 |

Middle Current (156 sq. mi.)

| Precipitation Gage | Percent of total area |
|---|---|
| Bunker | 63 % |
| Summersville | 7 |
| Birch Tree | 30 |

Owls Bend (395 sq. mi.)

| Precipitation Gage | Percent of total area |
|---|---|
| Bunker | 12 % |
| Birch Tree | 14 |
| Van Buren | 74 |

Lower Current (371 sq. mi.)

| Precipitation Gage | Percent of total area |
|---|---|
| Van Buren | 60 % |
| Doniphan | 40 |

Jacks Fork - Eminence (398 sq. mi.)

| Precipitation Gage | Percent of total area |
|---|---|
| Willow Springs | 23 % |
| Summersville | 39 |
| Birch Tree | 36 |
| Houston | 2 |

TABLE 4-1 (continued)

Current River - Eminence (1272 sq. mi.)

| Precipitation Gage | Percent of total area |
|---|---|
| Willow Springs | 7 % |
| Summersville | 35 |
| Bunker | 19 |
| Salem | 8 |
| Licking | 11 |
| Houston | 5 |
| Birch Tree | 15 |

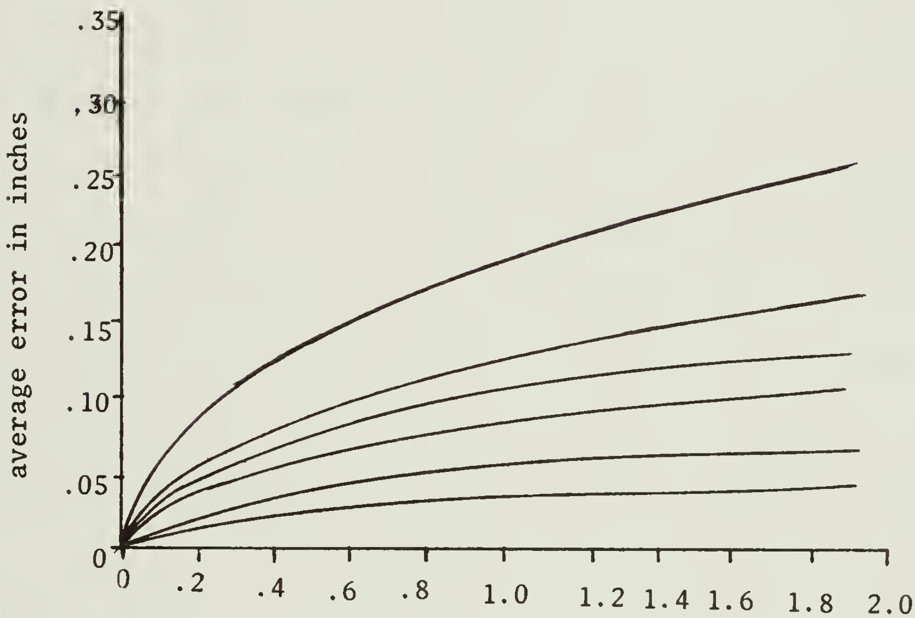
Current River - Van Buren (1667 sq. mi.)

| Precipitation Gage | Percent of total area |
|---|---|
| Van Buren | 18 % |
| Willow Springs | 6 |
| Summersville | 27 |
| Bunker | 17 |
| Salem | 6 |
| Licking | 8 |
| Birch Tree | 15 |
| Houston | 3 |

Current River - Doniphan (2038 sq. mi.)

| Precipitation Gage | Percent of total area |
|---|---|
| Doniphan | 8 % |
| Van Buren | 25 |
| Willow Springs | 5 |
| Summersville | 21 |
| Bunker | 14 |
| Salem | 5 |
| Licking | 7 |
| Birch Tree | 12 |
| Houston | 3 |

GRAPH OF ERROR ESTIMATE




storm precipitation in inches, 55-station mean (after Linsley, Kohler, and Paulus, 1958)

The graph is from a study on a 220 square mile area near Wilmington, Ohio, and was published by R. K. Linsley and M. A. Kohler. It shows the average error of average rainfall as a function of network density and amount of storm precipitation.

Taken from Hydrology for Engineers, Linsley, R.K., Kohler, Max A., and Paulhus, Joseph L., McGraw-Hill Book Company: New York, 1958, p. 32.

Figure 4-3

For example, in the Current River-Doniphan basin, the Van Buren raingage has an area weight of 25%. The total drainage area is 2,038 square miles, so the Van Buren gage must represent 51 square miles. Because it covers such a large area, a large error is introduced. A rough estimate from the graph gives, for a range of from 1.00 to 4.00 inches of gaged rainfall, an error of from .40 to .80 inch. Since Van Buren is weighted 25%, the greatest error introduced into the final precipitation value for the basin by the Van Buren station is (.25)x(.80) or .20 inch.

In the Jacks Fork subbasin, the Summersville gage has a weight of 39%. The total drainage area is 398 square miles. So the Summersville data must cover 155 square miles. The graph gives an estimate of .15 to .35 inches error. Thus, the greatest error introduced by Summersville into the final precipitation figure for the basin is .10 inch.

This procedure was followed for all the basins. The results can be found in Table 4-2. The first two columns list the basin and its area. Columns 3, 4, and 5 list the rain gage, the percent of the area of the basin which the rain gage must cover, and the area, in square miles, which the rain gage covers. Column 5 is found by multiplying columns 2 and 4. Column 6 is the amount of error in inches, determined from the graph, for a one inch rainfall. Column 7 is the error for a four inch rainfall. Column 8 is the error which that rain gage may introduce into the final precipitation figure for the basin, for a four inch rainfall. Column 8 is found by multiplying columns 4 and 7. The sum of the values in column 8 for a particular basin is the maximum error possible in the precipitation value for the basin.

In general, the weighted precipitation values for the subbasins have greater errors in periods of heavy rainfall. For a four inch monthly

TABLE 4-2

ERROR ESTIMATES

| 1<br>Drainage Basin | 2<br>Basin Area | 3<br>Rain Gage | 4<br>% Area | 5<br>Gage Area | 6<br>Error for 1 Inch Rain | 7<br>Error for 4 Inch Rain | 8<br>Error in Final Value |
|---|---|---|---|---|---|---|---|
| Spring Valley | 140 sq mi | Summersville | 100 % | 140 sq mi | .15 in | .35 in | .35 in |
| Upper Current | 578 | Bunker | 26 | 150 | .15 | .35 | .10 |
| | | Licking | 24 | 139 | .15 | .35 | .10 |
| | | Summersville | 23 | 133 | .15 | .35 | .10 |
| | | Salem | 18 | 104 | .10 | .30 | .05 |
| | | Houston | 9 | 52 | .08 | .15 | .01 |
| Middle Current | 156 | Bunker | 63 | 98 | .10 | .30 | .20 |
| | | Birch Tree | 30 | 47 | .08 | .15 | .05 |
| | | Summersville | 7 | 11 | .03 | .10 | .01 |
| Owls Bend | 395 | Van Buren | 74 | 292 | .20 | .40 | .30 |
| | | Birch Tree | 14 | 55 | .08 | .15 | .02 |
| | | Bunker | 12 | 48 | .08 | .15 | .02 |
| Lower Current | 371 | Van Buren | 60 | 223 | .20 | .40 | .25 |
| | | Doniphan | 40 | 148 | .15 | .35 | .15 |
| Jacks Fork | 398 | Summersville | 39 | 155 | .15 | .35 | .15 |
| | | Birch Tree | 36 | 143 | .15 | .35 | .15 |
| | | Willow Springs | 23 | 92 | .10 | .30 | .10 |
| | | Houston | 2 | 8 | .03 | .10 | .02 |

TABLE 4-2 (continued)

| 1<br>Drainage Basin | 2<br>Basin Area | 3<br>Rain Gage | 4<br>% Area | 5<br>Gage Area | 6<br>Error for 1 Inch Rain | 7<br>Error for 4 Inch Rain | 8<br>Error in Final Value |
|---|---|---|---|---|---|---|---|
| Current River - Eminence | 1272 sq mi | Summersville | 35 % | 445 sq mi | .40 in | .80 in | .30 in |
| | | Bunker | 19 | 241 | .20 | .40 | .10 |
| | | Birch Tree | 15 | 191 | .20 | .40 | .05 |
| | | Licking | 11 | 149 | .15 | .35 | .05 |
| | | Salem | 8 | 102 | .10 | .30 | .02 |
| | | Willow Springs | 7 | 89 | .10 | .30 | .02 |
| | | Houston | 5 | 64 | .08 | .15 | .01 |
| Current River - Van Buren | 1667 | Summersville | 27 | 450 | .40 | .80 | .20 |
| | | Van Buren | 18 | 300 | .40 | .80 | .15 |
| | | Bunker | 17 | 284 | .20 | .40 | .07 |
| | | Birch Tree | 15 | 250 | .20 | .40 | .06 |
| | | Licking | 8 | 133 | .15 | .35 | .03 |
| | | Salem | 6 | 100 | .10 | .30 | .02 |
| | | Willow Springs | 6 | 100 | .10 | .30 | .02 |
| | | Houston | 3 | 50 | .08 | .15 | .00 |
| Current River - Doniphan | 2038 | Van Buren | 25 | 509 | .40 | .80 | .20 |
| | | Summersville | 21 | 428 | .40 | .80 | .20 |
| | | Bunker | 14 | 285 | .20 | .40 | .05 |
| | | Birch Tree | 12 | 245 | .20 | .40 | .05 |
| | | Doniphan | 8 | 163 | .15 | .35 | .03 |
| | | Licking | 7 | 143 | .15 | .35 | .03 |
| | | Willow Springs | 5 | 102 | .10 | .30 | .02 |
| | | Salem | 5 | 102 | .10 | .30 | .02 |
| | | Houston | 3 | 61 | .08 | .15 | .00 |

rainfall total, errors can be as great as .4 inch. For a one inch monthly rainfall, errors are around .2 inch. However, since some errors will tend to cancel (error from one gage is positive, while that of another may be negative) errors are probably less than these maximum values.

## Comparison of Theissen and Mean Precipitation Values

Unweighted mean precipitation was calculated for the four gaged basins in order to compare these with Theissen values. The Theissen values for Current River-Doniphan seem to be smaller than the unweighted mean precipitation values. This is probably caused by the increased importance of Summersville in the Theissen values due to its heavy weight of 21%, which emphasizes the lighter rainfall of the northern part of the drainage basin.

The Theissen values are not consistently larger or smaller than mean precipitation values for the other three gaged basins.

One pronounced effect of the Theissen method is to make the average precipitation for all four basins more nearly equal. This is again due to the large emphasis on Summersville.

## Unweighted precipitation for areas outside the study area

Unweighted mean precipitation values were calculated for the drainage basins above discharge gaging stations at Bardley and Thomasville on the Eleven Point River, and Annapolis and Lesterville on the Black River. However, there is not a sufficient number of rain gages in and around these drainage basins to give figures accurate enough to be of value.

## Calculation of Monthly Discharge by Correlation

The first objective was to determine whether the rainfall-runoff relationship (for a particular month) for one subbasin could be applied to all other subbasins for that month.

There are many factors influencing runoff; temperature, soil moisture, vegetation and groundwater are the most important. Since all parts of the Current River basin are similar with respect to climate, topography, land cover, and geology, the conditions in one subbasin were assumed to be equivalent to those in all other subbasins.

### Data

Weighted monthly precipitation in inches for each subbasin was determined by the Theissen method, using U.S. Weather Bureau data from nine precipitation gaging stations in the basin. These weighted precipitation values are generally correct to two-tenths of an inch.

The monthly discharge in inches per square mile and in acre feet was taken from USGS discharge records. The data is generally accurate to within 10%.

This study covered a 10 year period, using monthly data for 12 months of each year, January 1961 to December 1970.

### Procedure

Monthly weighted precipitation in inches versus monthly discharge in inches per square mile at Jacks Fork, Current River-Eminence, Current River-Van Buren, and Current River-Doniphan was plotted on rectangular coordinate paper. The four points on each graph were labeled to indicate

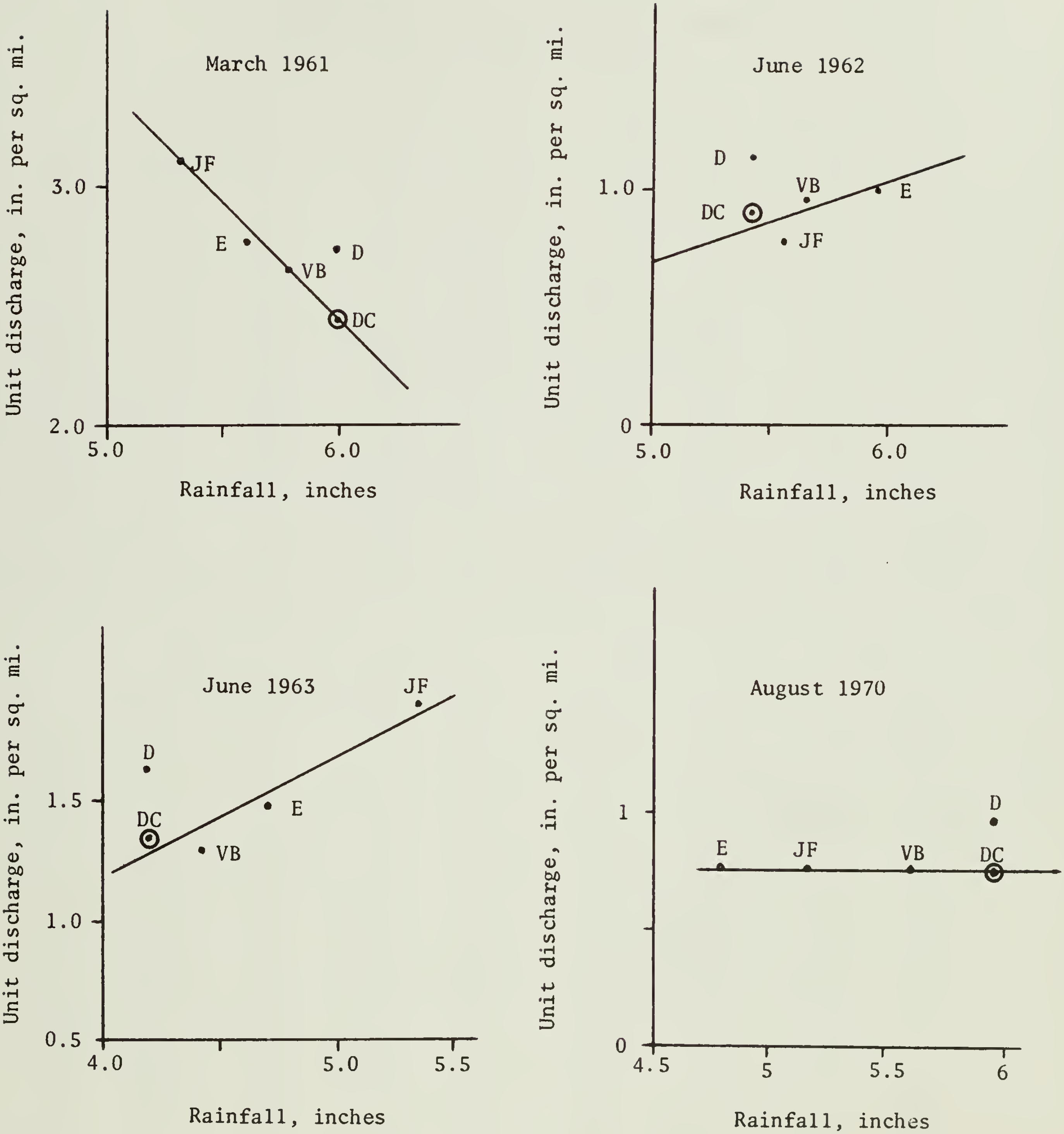
which subbasin is represented by each point. One hundred twenty graphs were prepared, one for each month for each of the ten years. An example is shown in Figure 4-4. All these graphs were used to determine the general rainfall-discharge relations, Figures 4-5, 4-6, discussed below.

Big Spring is located just below the drainage gage at Van Buren. Thus the flow from the spring is measured only at the Doniphan discharge gage. However, much of this underground flow has its source from outside the Current River drainage basin, and successful dye traces have been made from areas northeast and west of the drainage basin (Aley, 1972; personal communication). To insure that the amount of surface discharge from the basin reflects rainfall over the basin only, this underground flow should not be considered. The monthly discharge in acre feet of Big Spring (which is measured by a gage) was subtracted from the monthly discharge in acre feet at Doniphan. This value was then converted into inches per square mile, using the entire Current River-Doniphan basin as the area over which the discharge was spread. These "corrected Doniphan discharge" values are tabulated in an Appendix. The corrected values were plotted on the graphs, in addition to the actual measured discharge. In judging what linear relationships exist and in drawing the lines on the graphs to represent these relationships, the corrected Doniphan discharge values were the points considered, and the points representing actual discharge from Doniphan were ignored. In general this procedure did seem to result in a greater linear correspondence of points.

The linear equation of each line, in the form Y=A(X)+B was determined, where

Y = discharge in inches per square mile
X = weighted precipitation in inches

RAINFALL-RUNOFF GRAPHS




JF Jacks Fork VB Van Buren E Eminence
D Doniphan DC Doniphan - Corrected

Figure 4-4, Examples of Rainfall-Unit Discharge Graphs

TABLE 4-3

EQUATIONS OF RAINFALL-DISCHARGE RELATIONS

IN THE FORM Y=A(X)+B

| | 1961 | | 1962 | | 1963 | | 1964 | |
|---|---|---|---|---|---|---|---|---|
| | A | B | A | B | A | B | A | B |
| Jan. | 0.00 | .55 | 1.30 | -3.95 | 0.00 | .65 | .80 | -0.20 |
| Feb. | 0.00 | .70 | .10 | 1.00 | 0.00 | .45 | 0.00 | .50 |
| Mar. | -1.00 | 8.50 | 0.00 | 2.25 | .30 | .10 | .30 | .25 |
| Apr. | -1.00 | 5.60 | .20 | 1.10 | 0.00 | .90 | .85 | -2.70 |
| May. | -1.00 | 13.50 | -0.20 | 2.40 | 1.25 | -8.05 | 0.00 | .90 |
| June | .40 | .10 | .30 | -1.00 | .50 | -0.80 | 0.00 | .65 |
| July | 0.00 | 1.00 | 0.00 | .65 | 0.00 | .90 | .20 | -0.10 |
| Aug. | 0.00 | .65 | 0.00 | .50 | 0.00 | .65 | .05 | .35 |
| Sept. | 0.00 | .57 | .20 | -0.25 | 0.00 | .45 | .05 | .30 |
| Oct. | 0.00 | .50 | .30 | -0.30 | 0.00 | .45 | 0.00 | .45 |
| Nov. | 0.00 | .55 | 0.00 | .55 | 0.00 | .55 | 0.00 | .45 |
| Dec. | .25 | -0.10 | 0.00 | .55 | 0.00 | .50 | .50 | -0.15 |

| | 1965 | | 1966 | | 1967 | | 1968 | |
|---|---|---|---|---|---|---|---|---|
| | A | B | A | B | A | B | A | B |
| Jan. | .35 | -0.25 | 1.20 | -3.30 | 0.00 | .90 | .75 | -0.65 |
| Feb. | .35 | -0.20 | 1.80 | -7.60 | 0.00 | 1.20 | .65 | .40 |
| Mar. | .20 | .10 | .40 | .80 | .60 | .10 | -0.10 | 2.30 |
| Apr. | 1.40 | -5.50 | .70 | -2.50 | .15 | .40 | 0.00 | 2.65 |
| May | 0.00 | 1.05 | .15 | 1.75 | .20 | .70 | .80 | -2.30 |
| June | .45 | -0.80 | 0.00 | .75 | 0.00 | .65 | 0.00 | .90 |
| July | 0.00 | .50 | 0.00 | .60 | 0.00 | .60 | 0.00 | .60 |
| Aug. | 0.00 | .45 | .25 | -0.70 | 0.00 | .45 | 0.00 | .60 |
| Sept. | .25 | -0.75 | 0.00 | .55 | 0.00 | .45 | 0.00 | .55 |
| Oct. | 0.00 | .60 | 0.00 | .55 | 0.00 | .55 | 0.00 | .50 |
| Nov. | 0.00 | .45 | .20 | -0.15 | 0.00 | .55 | 1.90 | -13.00 |
| Dec. | 0.00 | .55 | 0.00 | .95 | 0.00 | 2.55 | 2.20 | -7.80 |

TABLE 4-3 (continued)

EQUATIONS OF RAINFAL-DISCHARGE RELATIONS

IN THE FORM Y=A(X)+B

| | 1969 | | 1970 | |
|---|---|---|---|---|
| | A | B | A | B |
| Jan. | -2.30 | 18.15 | 0.00 | .60 |
| Feb. | 4.30 | -5.20 | 0.00 | .50 |
| Mar. | .45 | .35 | .10 | .80 |
| Apr. | 1.00 | -2.65 | 1.20 | -3.00 |
| May | .45 | .75 | -0.40 | 3.00 |
| June | 0.00 | .80 | .40 | -1.40 |
| July | 0.00 | .70 | 0.00 | .55 |
| Aug. | 0.00 | .60 | 0.00 | .75 |
| Sept. | 0.00 | .55 | 0.00 | .75 |
| Oct. | 0.00 | .55 | .60 | -1.95 |
| Nov. | 0.00 | .50 | .05 | .95 |
| Dec. | 0.00 | .55 | 0.00 | .75 |

The coefficients A and B for each month are listed in Table 4-3.

The linear relationships drawn were those indicated by the points, even though seven of these were negatively sloping lines, such as those of March, April, and May 1961 (Table 4-3). Although, in general, discharge should increase with increasing rainfall, these lines suggest otherwise. This could be due to inaccurate discharge data in times of high flow, Theissen weighted precipitation values which have a large error, or it may be a true relationship caused by special environmental factors. In any case, these negatively sloping relationships do not represent the usual conditions throughout the basin.

These relationships were tested by using them to calculate the discharge in the various subbasins, adding these values to find the calculated discharge from Current River-Eminence, Current River-Van Buren, and Current River-Doniphan basins, and then comparing the calculated and measured discharge of these basins.

Discharge in inches per square mile from each subbasin (except Jacks Fork, which is measured) was found by substituting the weighted precipitation value in the equation $Y = A(X) + B$ for each month. The value Y in inches per square mile was converted into acre feet of discharge by multiplying it by the area of the subbasin and by a conversion factor of 53.3 acre-feet per inch on one square mile.

Calculated and measured discharge can be compared for the Current River-Eminence, Current River-Van Buren, and Current River-Doniphan basins. The calculated discharge of Upper Current, Spring Valley, Middle Current, and the measured discharge of Jacks Fork were summed and compared to the discharge measured by the gage at Current River-Eminence. Then calculated discharge of the Owls Bend subbasin was added to the

sum, and this was compared with the discharge measured by the gage at Van Buren. Next, the calculated discharge of the Lower Current subbasin was added to the sum, and this figure was compared to the corrected measured discharge at Doniphan (Doniphan discharge minus Big Spring discharge). The calculated discharge, measured discharge, and percent error between the two for each month at each of the three gages was tabulated and compared. The significance of the results is discussed in a later paragraph.

The procedure described above is outlined in Table 4-4, which shows the calculations for two months. Column 4, "Calculated Discharge" in acre feet was found by substituting the values in column 3, weighted precipitation, into the equation $Y = A(X) + B$ ,and then multiplying the resulting "Y" by the area (column 2) and the conversion factor 53.3. Column 5 lists measured discharge as published by the USGS. The sum of the calculated discharges is compared to the measured discharge, and the error expressed as a percent of the measured discharge is listed in column 6.

## Discussion of Results

Two types of discharge are reflected by the runoff relationships (Table 4-3). One type reveals a "base flow" condition in the basin, as shown by the data for August 1970. (The instances of base flow are easily found in Table 4-3 as those months when the coefficient A equals zero.) Even though monthly rainfall varied quite a bit from basin to basin, the discharge per square mile remained a constant value. This value is the base flow, which is here defined as the average monthly discharge per square mile which results predominantly from spring discharge and groundwater seepage. This condition occurs most commonly in the hot summer months, when dry ground and high evapotranspiration stop the rain-

fall from reaching the river as runoff. Water Resources Report 25, Base Flow Recession Characteristics and Seasonal Low Flow Frequency Characteristics for Missouri Streams (Skelton, 1970), has calculated the upper limit of base flow at Doniphan to be 1800 cfs, or .99 inches/sq. mi. Almost all of the 65 months in the study which indicated base flow conditions have discharge values less than this maximum flow. Base flow on graphs varied from .45 to 1.00 inches/sq. mi. In many of the graphs, Jacks Fork had significantly less unit discharge than that of the other three (.10 to .20 inches/sq. mi. less), suggesting a smaller base flow than is normal in the rest of the basin. This may indicate that some of the rain that falls in Jacks Fork basin leaves via subsurface channels, most probably to Big Spring.

The other type of discharge is a "run-off" condition in which rainfall does affect discharge. The graph of June 1963 is an example of this. As rainfall increased, the resulting discharge increased. Although this example shows discharge values well above the maximum limit of base flow, many of the other graphs show a rainfall-discharge increase with discharge values below .99 inches per square mile.

## Error Estimates

If the value for base flow is in error by .05 inches/sq. mi., the maximum error in calculated discharge is 10%. This is within the desired accuracy, because the USGS discharge gages are accurate to within 10%. Most of the graphs could be drawn within an error range of .05 inches/sq. mi. For a few, however, this accuracy was not possible. The calculated discharge is in error by less than 10% in three-fourths of the months studied. The percent error in the two examples in Table 4-4 is signifi-

TABLE 4-4

CORRELATION PROCEDURE FOR 2 MONTHS

August 1970

The equation for August 1970 is $Y=(0)(X)+.76$

| 1<br>Subbasin | 2<br>Area | 3<br>Weighted Ppt | 4<br>Calculated Dis | 5<br>Meas Dis | 6<br>% Error |
|---|---|---|---|---|---|
| Upper Cur | 578 sq mi | 3.47 in | 23414 acre ft | | |
| Spring V | 140 | 5.20 | 5671 | | |
| Middle Cur | 156 | 4.51 | 6319 | | |
| Jacks Fork | 398 | 5.19 | (16500) | 16500 | |
| CR-Eminence | 1272 | | 51904 | 52610 | -1% |
| Owls Bend | 395 | 8.14 | 16001 | | |
| CR-Van Bur | 1667 | | 67905 | 68530 | -1% |
| Lower Cur | 371 | 7.74 | 15028 | | |
| CR-Doniphan | 2038 | | 82933 | 81890 | 1% |

June 1963

The equation for June 1963 is $Y=(.50)(X)-.81$

| 1<br>Subbasin | 2<br>Area | 3<br>Weighted Ppt | 4<br>Calculated Dis | 5<br>Meas Dis | 6<br>% Error |
|---|---|---|---|---|---|
| Upper Cur | 578 sq mi | 4.51 in | 44363 acre ft | | |
| Spring V | 140 | 4.48 | 10745 | | |
| Middle Cur | 156 | 3.82 | 9063 | | |
| Jacks Fork | 398 | | (40680) | 40680 | |
| CR-Eminence | 1272 | | 104851 | 100900 | 4% |
| Owls Bend | 395 | 3.48 | 19790 | | |
| CR-Van Bur | 1667 | | 124641 | 119900 | 4% |
| Lower Cur | 371 | 3.08 | 14633 | | |
| CR-Doniphan | 2038 | | 139274 | 148000 | -6% |

cant only in that it is less than 10%. Accuracy to 1% was found to be not possible with the data and methods used.

## Conclusion

Correlation of unit discharge with precipitation on a monthly basis is possible for the Current River drainage basin. A linear relationship between precipitation and discharge can be found for each month. This relationship can be used to make a very close estimate of the discharge of various subbasins.

## Recommendations for further study

Further study should concentrate on relating the monthly base flow conditions (as defined here) to low flow studies such as the low flow study of the Jacks Fork (published in the *Water Resources Data for Missouri*, 1970), and to base-flow recession information.

# Determination of General Rainfall-Discharge Relations

The second objective in this study was to find a general relationship between monthly rainfall and monthly discharge, and to ascertain whether discharge could be calculated *without* first knowing the discharge in several other basins.

## Variables Considered

Three variables affecting discharge were taken into consideration: the total rainfall during the particular month in question, the total rainfall during the preceding month, and the time of year.

The total rainfall during the month studied is, of course, the most important variable. Except during periods of base flow conditions, an increase in rainfall from basin to basin results in an increased discharge. Thus, a method is needed to determine base flow conditions, and to determine a general linear relationship between rainfall and discharge.

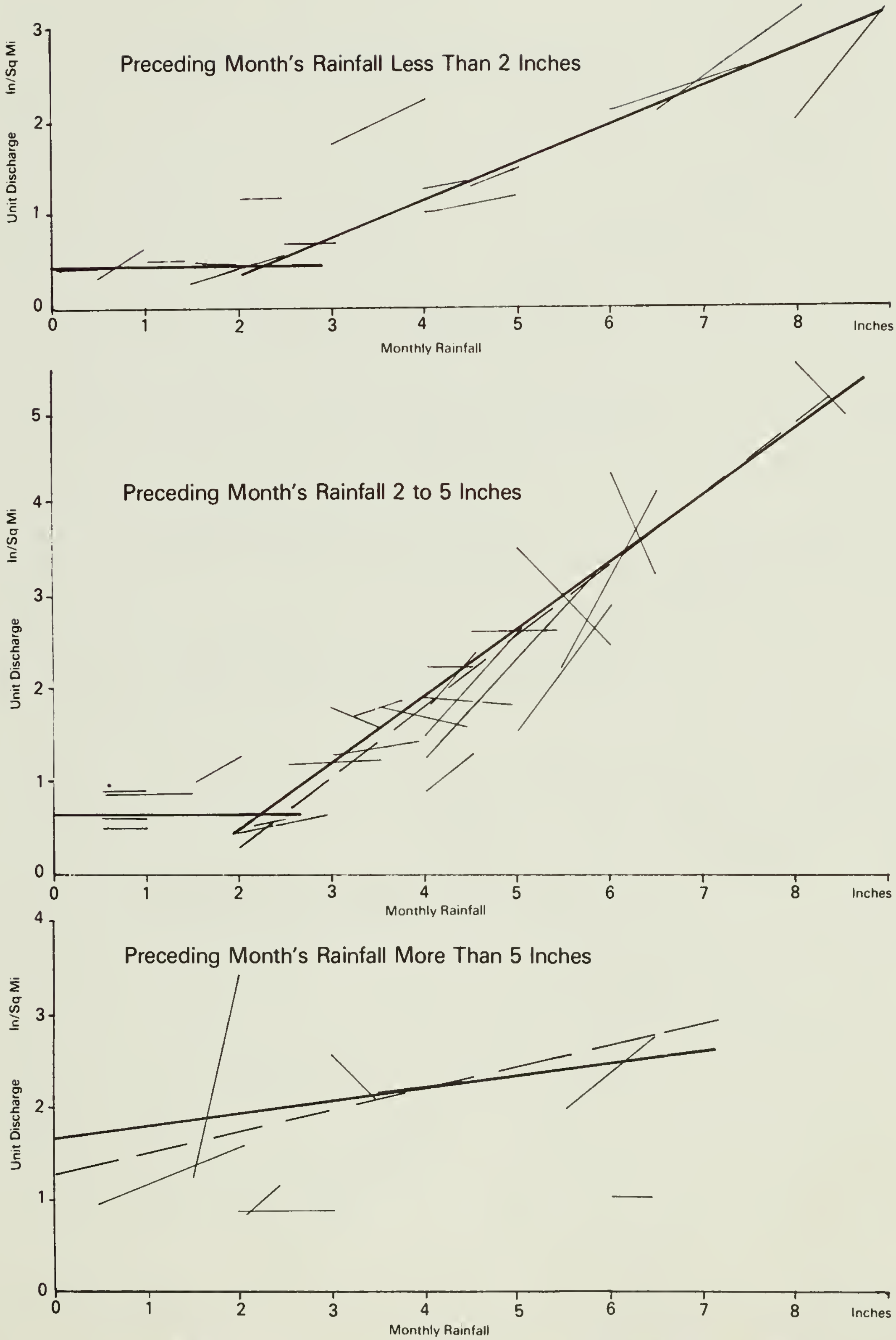
The total inches of rainfall of the preceding month is very important, because it indicates the amount of soil moisture, which in turn affects the amount of rainfall which the ground can absorb. The resulting runoff may differ considerably depending upon whether the preceding month's rainfall was one or seven inches.

The "time of year" actually includes many variables, such as temperature and requirements of evapotranspiration. The use of the individual month may accurately express these variables as one variable. The relation of the "time of year" to discharge should be determined.

Procedure

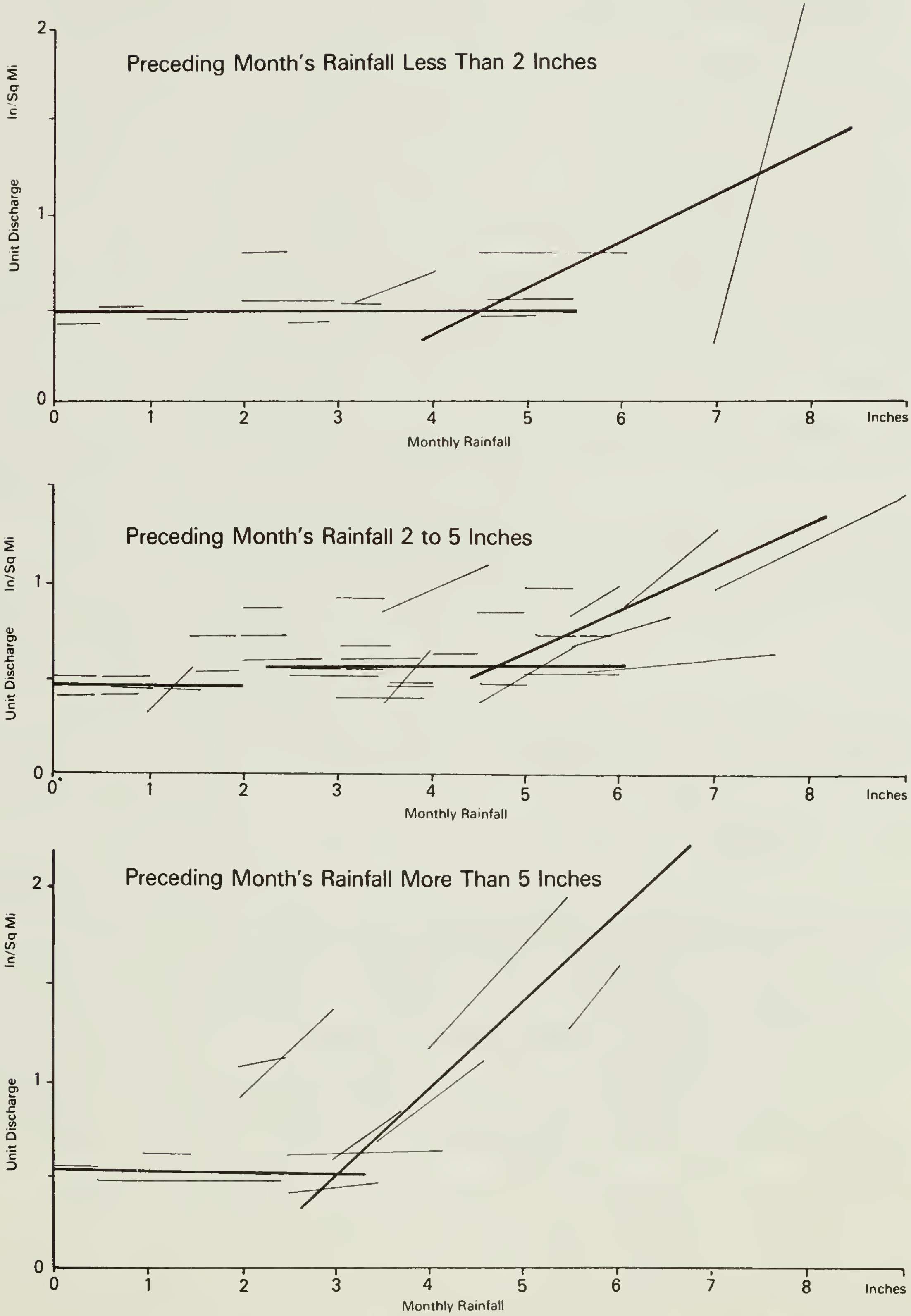
Composite graphs were made of total monthly discharge, in inches per square mile, versus total monthly rainfall, in inches (Figure 4-5 and 4-6). These were made by compiling all of the previous monthly graphs into two sets of three groups each. The months were first divided into two "times of the year": January through May (five months), and June through December (seven months). This is a very broad grouping, and may obscure any general tendencies which would otherwise be apparent.

For each time group, three graphs were made, depending upon the preceding month's rainfall. The following divisions were made: rainfall less than 2 inches, rainfall between 2 and 5 inches, and rainfall greater than 5 inches. The relationships were plotted with the horizontal axis




**RAINFALL-RUNOFF RELATIONSHIPS**

Figure 4-5, January-May Relationships




**RAINFALL-RUNOFF RELATIONSHIPS**

Figure 4-6, June-December Relationships

representing the rainfall of the month under consideration. The data plotted were obtained from the individual graphs made for Objective 1. Note that each relationship has a definite horizontal range.

Several lines were drawn on the graphs to represent the general relationships suggested by the trends of the individual monthly relationships. For example, on Graph #1, January through May (with preceding month's rainfall less than two inches) two general trends are apparent. The first is a base flow condition, when rainfall of the month in question is between 0 and 2 inches. The second trend is a positive linear relationship with discharge increasing with rainfall from 2 inches up to the maximum rainfall on the horizontal axis.

Graph #3 has only one poorly defined trend apparent. Graph #5 has three trends; the first two are base flow conditions, and the third is a sloping linear relationship.

The linear relationships which represent the general rainfall-discharge relationships are summarized, in Table 4-5, in terms of the equations of the lines.

## Results

The unit discharge from each subbasin for each month was calculated using the general equation assigned to that month on the basis of the three variables. The discharges of the proper subbasins were summed and compared to the measured discharge at the three gaging stations. Percent error between the calculated and measured value was also determined.

A little more than one-third of the months showed an error of 10% or less. Another one-third had an error between 10% and 20%. The last one-third had a large error, greater than 20%. The errors are not concentrated in any special month.

TABLE 4-5

GENERAL RAINFALL-DISCHARGE RELATIONSHIPS

FOR: June-July-August-September-October-November-December

Preceding month less than 2 inches

| | |
|---|---|
| 0 to 2 inches | Y = 0(X) + .50 |
| 2 to 5 inches | Y = 0(X) + .50 |
| 5 on up | Y = .50(X) - 2.15 |

Preceding month 2 to 5 inches

| | |
|---|---|
| 0 to 2 inches | Y = 0(X) + .50 |
| 2 to 5 inches | Y = 0(X) + .60 |
| 5 on up | Y = .50(X) - 2.25 |

Preceding month greater than 5 inches

| | |
|---|---|
| 0 to 2 inches | Y = 0(X) + .55 |
| 2 to 5 inches | Y = .95(X) - 2.60 |
| 5 on up | Y = .95(X) - 2.60 |

FOR: January-February-March-April-May

Preceding month less than 2 inches

| | |
|---|---|
| 0 to 2 inches | Y = 0(X) + .45 |
| 2 to 5 inches | Y = .40(X) + .45 |
| 5 on up | Y = .40(X) + .45 |

Preceding month 2 to 5 inches

| | |
|---|---|
| 0 to 2 inches | Y = 0(X) + .65 |
| 2 to 5 inches | Y = .70(X) + .85 |
| 5 on up | Y = .70(X) + .85 |

Preceding month greater than 5 inches

| | |
|---|---|
| 0 on up | Y = .15(X) + 1.60 |

Recommendations for further study

1. The relation of the preceding month's rainfall to soil moisture should be determined.
2. The "time of year" should be considered in smaller divisions such as the four seasons.
3. The "time of year" should be broken down into its component variables, and each of these treated separately.
3. The months with large percent errors in the calculations should be examined to determine the cause of the large error (and thus to determine an important variable which was not considered earlier).

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# Section V

# SOURCES OF LARGE SPRINGS

Knowledge of the sources of the large springs in the basin is vital to an understanding of the Current River Basin's water resources. To investigate possible sources of these springs, two major groundwater tracing studies were undertaken for this report. One investigated the sources in the northern and northeastern half of the Current River basin, especially for Montauk Springs and Blue Spring. The uniquely picturesque Blue Spring is the second largest spring in the Current River while Montauk Springs, at the head of the Current River, is the focal point for one of the Riverway's main fishing and camping areas. Work on this northern study was done by Dr. Maxwell and Mr. David Hoffman. The other tracer study which concentrated on Big Spring and the southern half of the basin was done by Mr. Thomas Aley, hydrologist for the Ozark Underground Laboratory.

## Licking-Montauk Area

In preparation for the chemical tracer studies planned for the spring of 1972, exploratory field trips were made in the Licking-Montauk area and in the general area of Logan Creek, including Dickens Valley near Ellington. In these places sites were carefully checked for suitability as the injection points for tracers.

Mounty Spring, on the Maples, Missouri 1:24,000 topographical map (TWP 32N, R8W, Sect. 25 center) appeared to be most suitable of the springs that were looked at, but beavers had dammed the stream. Past this dam, the water disappeared into the stream-bottom alluvium. If a hole were

dug in the channel bottom downstream from the dam, it might intercept enough stream flow to provide a good injection site.

The second most likely looking site found in the Licking area is located in TWP 33N, R8W, on the line between Sections 32 and 33. Here was found a large broad sinkhole approximately 600' in diameter and twenty feet deep with gently sloping sides and a generally flat bottom. The nearly flat bottom slopes very gently to a swallow-hole approximately one foot in diameter. It is located in an area of approximately sixty acres of rich pastureland on whch fifty to more than one hundred cattle are grazed. During rainy seasons almost all the surface runoff disappears down this sinkhole, and a trace done here <u>during</u> a heavy rainstorm would be particularly valuable. There is no other naturally available water source.

The location of this sinkhole on the upland between Pigeon Creek at the head of the Current River and the northwestward flowing headwaters of Spring Creek increases its importance in delineation of the subsurface divide. It is in an area of several sinks aligned north-south along the divide.

Another prospectively significant site was tentatively named Mounty Sink (TWP 32N, R8W, Sect. 35, NW¼ of NW¼). It is a steep-sided sinkhole, 400 feet in diameter and 30 feet deep, located in a forested area. Large trees (up to 14 inches diameter) grow in the sink. There is evidence of active subsidence, such as tilted small trees in the bottom of the sink. There are cave-like openings under outcropping ledges in the east and south rims of the sink. If the cave openings could be enlarged, they might provide access to subsurface drainage suitable for a trace. Otherwise this sinkhole should be re-examined occasionally for signs of future movement or enlargement of the bottom.

In addition to those sites listed above, several other sites were explored that might be suitable as injection points for traces. All were found to be less satisfactory than the three described above. One, an unnamed spring tributary to Bean Creek, is located in TWP 32W, R8W, Sect. 11 on the Licking quadrangle. This spring has no well-defined outlet. It emerges as a broad seep over a large swampy area. The stream did not sink or disappear in the half mile below the spring. Access was not permitted to follow the stream further. Another less than satisfactory site was on a road crossing a stream in SE¼, Sect. 34, TWP 33N, R8W (Maples 7½-minute quadrangle). The road was very poor and the stream (upper Pigeon Creek) was dry, with heterogeneous material from fine sand to small boulders. Downstream, at Pigeon Creek Ford (TWP 33N, R8W, Sect. 26, SE¼ of SE¼), intermittent standing pools of water with no discernible flow were observed. Fine textured silt and sand in the channel indicates no strong sinking of the creek in this vicinity. Also examined was a valley called "Watered Hollow" by the farmer who owns the land (NW¼, Sect. 25, TWP 33N, R8W). Although the owner said there were several very small springs in the valley, it was dry when visited in November, 1971.

Logan Creek-Dickens Valley Area

Most of the effort to find spring sources in the north-eastern part of the Current River Basin was concentrated in the Logan Creek-Dickens Valley area near Ellington. Although Logan Creek does not flow into the Current River, the upper portion of Logan Creek flows southward from near the town of Reynolds in a nearly straight line toward the Current River. Approximately six miles north of Blue Spring on the Current River, Logan Creek makes a sharp right angle turn (elbow bend) to the east and

flows through Ellington southeastward to the Black River. Dickens Creek, which flows southward approximately parallel to and to the east of Logan Creek, joins Logan Creek between the elbow bend and Ellington.

Throughout its upper course Logan Creek flows year round. When it reaches a point near the historic Latter Day Saints Church, near the former Chitwood store (TWP 30N, R2W, Sect. 11), the stream sinks underground into its gravel bed. From this point downstream past the elbow bend nearly to Dickens Valley, Logan Creek is usually dry. Surface flow occurs only during times of heavy prolonged rainfall. From the Latter Day Saints Church downstream the broad flat stream channel is more than fifty feet wide, entrenched eight to twelve feet below wide flood-plain terraces several hundred feet wide. The stream channel is filled with coarse sand and gravel which is locally excavated for construction use.

A chemical dye trace completed in 1969 (Feder and Barks, 1972) showed that water from Logan Creek resurfaced at Blue Spring on the Current River. This, together with the facts that Logan Creek is obviously loosing water underground, that Blue Spring is the second largest spring in the Riverways and one of its major attractions, and that development of Missouri's new lead mining belt is creating potential sources of pollution in the headwaters of Logan Creek, focused attention on this area.

Numerous small sinkholes exist in the Dickens Valley area. Many of these are presently inactive and apparently sealed by silt and clay and have been developed by local residents for reservoir and stockwatering use. Of the many sinkholes examined in Dickens Valley and the long irregular ridge between Dickens and Logan Valley, only three are thought to have particular significance to this study. In Township 30N, Range 1W, Sections 29 and 30, are three large sinkholes aligned approximately

N55°W. The southeasternmost, approximately one hundred feet in diameter and thirty feet deep, is the deepest. Disturbed soil and twisted vegetation in the conical bottom indicate active subsidence. The middle sinkhole is more than two hundred feet in diameter, but less than five feet deep, nearly flat floored, and has a shallow, swampy ephemeral pond in one end. The northwestern sink, roughly conical, eighty feet wide and twenty feet deep, has a few small bouldery outcrops in its side and some minor evidence of active subsidence. These sinks seem to be aligned with the lower portion of Dickens Valley and are aligned with Latter Day Cave described below. It is quite probable that they lie on the trace of the Ellington fault, which may have considerable influence on subsurface drainage in the area. The exact location and nature of the Ellington fault is controversial, according to current geologic literature (Thornton, 1963; McCracken, 1971; Feder & Barks, 1972).

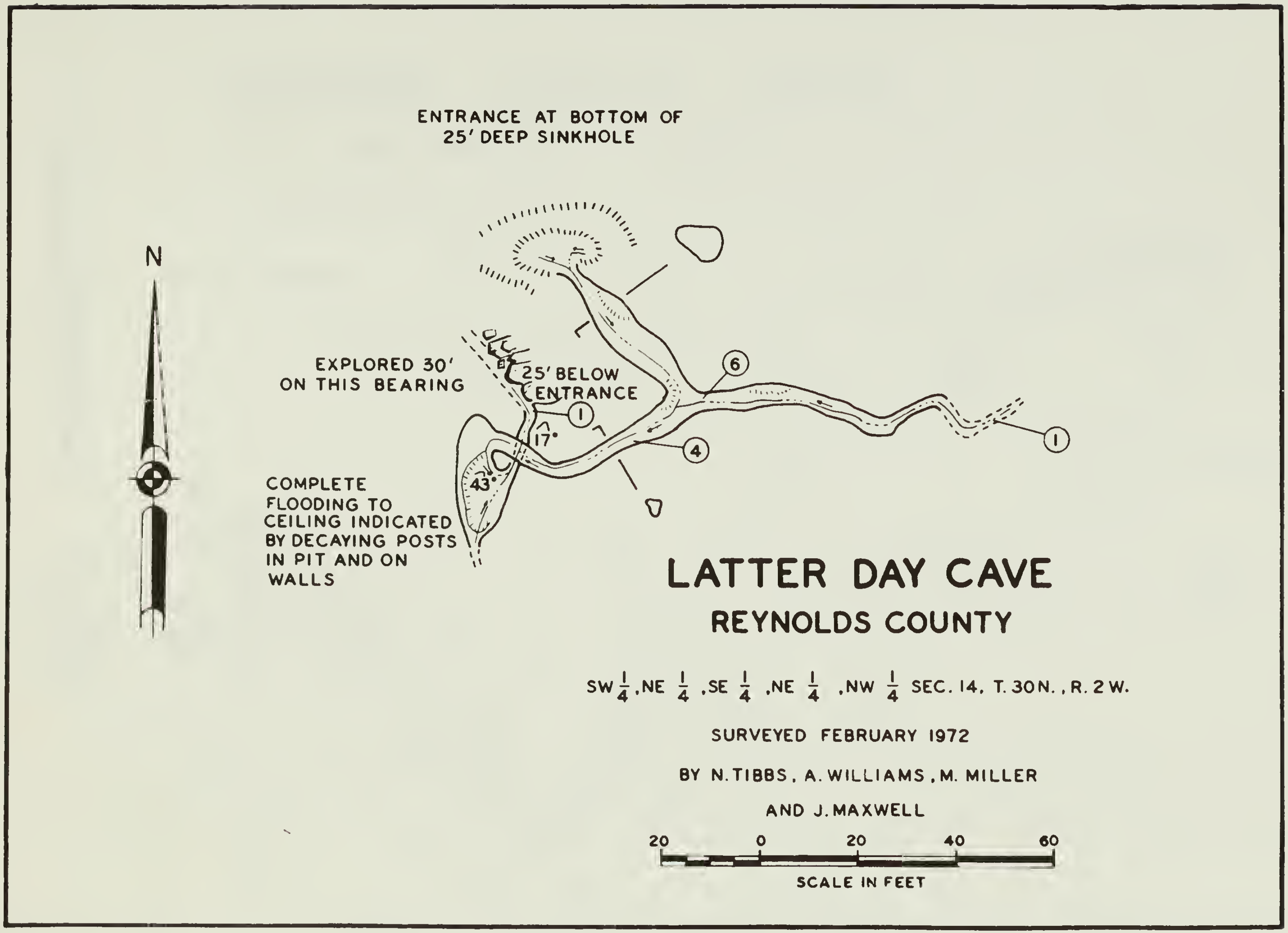
One other feature in Dickens Valley, Cave Spring Hollow (TWP 30N, R1W, Sect. 9 and Sect. 16, unnamed on the Corridon SE 7½-minute map), may be useful to future studies of spring sources. In this valley, three-eighths of a mile north of the south edge of the section, a small spring produces a flow which travels less than forty feet before sinking into the gravelly stream bed. The stream channel above and below the spring seems to be dry except during heavy rains. This spring might provide enough flow in a wet season to permit dye injection into the creek bed.

In Logan Valley, several sinks and caves were surveyed in preparation for groundwater tracing. One of the smaller sinks is in the channel of Logan Creek 700 feet downstream from the Latter Day Saints Church. It consists of two elongate shallow connected depressions, four to six feet wide, two to three feet deep, with a combined length of approximately

twenty feet. The gravel in these depressions is unusually coarse, 2 to 10 inches in diameter, with a conspicuous absence of accompanying sand. When the flow in upper Logan Creek is a little greater than normal, surface flow extends past the Church to fill these depressions for a few hours. Flow rarely extends beyond these depressions except when the entire channel is flooded.

A large previously unnamed and unmapped sinkhole and cave on the west bank of Logan Creek near the Latter Day Saints Church was surveyed and provisionally named "Latter Day Cave" (Figure 5-1). The sinkhole is near the west side of the valley in a clump of trees on a flood plain terrace, approximately 2100 feet southwest from the Church. It is 37 feet wide and 25 feet deep, with a cave entrance five feet high in the south side of the rubble-filled bottom. Logs and other debris at the inner end of a short tube-like passage indicated that flood water enters the cave when Logan Creek overflows its channel. Removal of the debris provided access to a steeply inclined tunnel which leads downward toward the rubble-filled sinkhole. Large boulders and angular cobbles, apparently from the collapsed sinkhole, block further passage. The lowest point reached was fifty feet below the surface of the floodplain.

Another small cave, 600 feet south of Latter Day Cave, on the west bank of Logan Creek, was surveyed and named "Logan Creek Cave" (Figure 5-2). The significance of this cave to the project was the development of a small sinkhole in the sand floor of the cave. When the cave was first examined in February and March, 1972, the floor on the south side of the cave, 40 to 50 feet in from the mouth, was smooth, medium to coarse sand which had been washed into it during unusually high floods. Sometime during late spring or early summer of 1972 and area 5 by 12 feet


ENTRANCE AT BOTTOM OF
25' DEEP SINKHOLE
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EXPLORED 30'
ON THIS BEARING
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ENTRANCE
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4
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43°
COMPLETE
FLOODING TO
CEILING INDICATED
BY DECAYING POSTS
IN PIT AND ON
WALLS
LATTER DAY CAVE
REYNOLDS COUNTY
SW $\frac{1}{4}$, NE $\frac{1}{4}$, SE $\frac{1}{4}$, NE $\frac{1}{4}$, NW $\frac{1}{4}$ SEC. 14, T. 30N., R. 2W.
SURVEYED FEBRUARY 1972
BY N. TIBBS, A. WILLIAMS, M. MILLER
AND J. MAXWELL
20 0 20 40 60
SCALE IN FEET

Figure 5-1

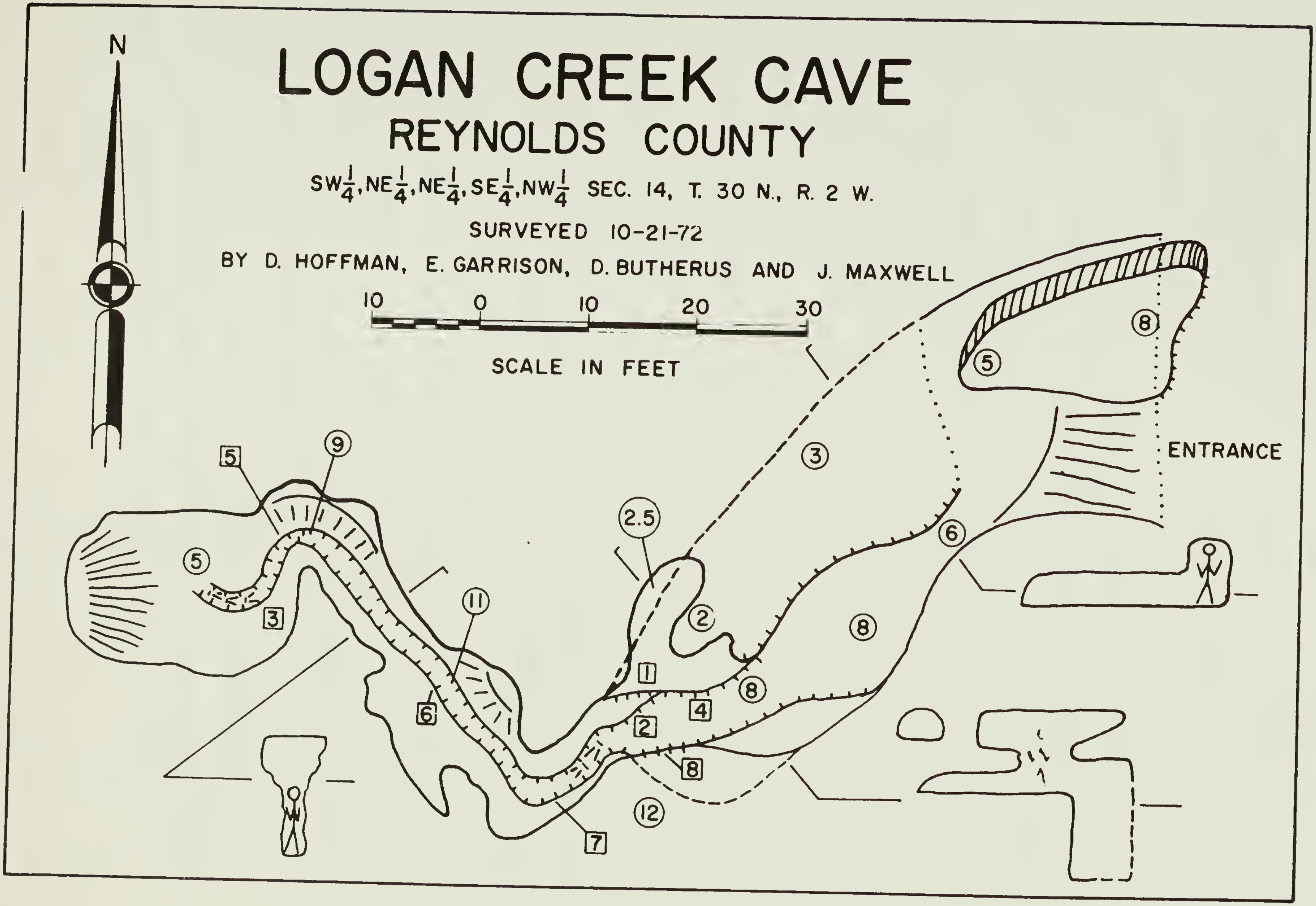
LOGAN CREEK CAVE
REYNOLDS COUNTY
SW$\frac{1}{4}$, NE$\frac{1}{4}$, NE$\frac{1}{4}$, SE$\frac{1}{4}$, NW$\frac{1}{4}$ SEC. 14, T. 30 N., R. 2 W.
SURVEYED 10-21-72
BY D. HOFFMAN, E. GARRISON, D. BUTHERUS AND J. MAXWELL
10 0 10 20 30
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Figure 5-2

began to subside, apparently caused by removal of sand from below. As the subsidence continued, a network of tree roots which had been growing horizontally through the loose sand was exposed. Their size, up to 1½ inches diameter, indicated that this subsidence was an infrequent event. By October, 1972 the sand floor had been lowered six to eight feet, indicating active drainage of sand into deeper chambers of unknown extent.

A third sinkhole, 200 feet west of the south end of Ellington Municipal Airport, appeared to be completely choked with debris when first examined, although local residents reported a cave in the sink had been entered in the past. A vertically-walled gully four to ten feet deep and six feet wide leads from near the west edge of the airport runway to the mouth of the sinkhole. Several man-days of work with saws, axes, and a winch were spent removing enough logs to reveal a 2 foot by 5 foot bedrock slot which opened into a spacious 5 by 15 foot vertical shaft 30 feet deep. A large cave passage 10 to 30 feet high and 6 to 20 feet wide continued from the bottom of the shaft 180 feet generally southward and 10 feet lower to a room where the rock ceiling descended abruptly to a mud and water-filled siphon at floor level.

Tracer tests were begun in the spring of 1972, after the necessary equipment, instruments and supplies had been built, borrowed, and purchased respectively. One of the objectives of the tracer studies was to attempt to confirm the trace done by Feder and Barks (1972). They had injected fluorescein in flowing water in Logan Creek approximately one mile upstream from the Latter Day Saints Church. At that time the stream flow was disappearing into its channel bed a few hundred feet upstream from the church.

They reported that they detected the dye about three weeks later at two widely separated sites: six miles east of Ellington in Logan Creek,

and ten miles south at Blue Spring on the Current River near Powder Mill. Their identification of the dye depended upon fluorometer readings; no visible fluorescein was detected. The fluorometer readings for samples from other sites were one-half to one-fifth of those for samples extracted from lower Logan Creek and Blue Spring. A second attempt by Feder and Barks to repeat their trace was inconclusive because most of their detectors were lost or stolen (Feder, 1972).

For the present study, charcoal dye-collectors were placed on March 11th at four locations in Logan Creek (upstream from Dickens Valley, in the discharge tank of an Ellington city well pumping from Logan Creek alluvium, at Morris Spring and at the ford below Morris Spring), and at five sites on the Current River (Powder Mill Spring, Cave Spring at Powder Mill Cave, Blue Spring, the mouth of Carr Creek, and Gravel Spring). Fluorescein dye was injected into Logan Creek on the night of April 11th at a farm road ford crossing the Creek 1500 feet due north from the church. This may have been further south than the point Feder and Barks used, but was upstream from the point where the stream sank during their test. On the 11th, before the dye was injected, a control series of charcoal dye detectors was retrieved from each collection point to measure the natural background level of fluorescence. Fresh detectors were installed at the same time.

A succession of unusually heavy rainstorms began three days after the April 11th injection and caused persistent flooding in the Current River. The heaviest rain occurred on the 20th and 21st, causing Logan Creek to flood. Many of the dye-collectors became inaccessible and a few were destroyed. The large flow in the usually dry middle section of Logan Creek exceeded the 10-year discharge for this Creek, and the 16-

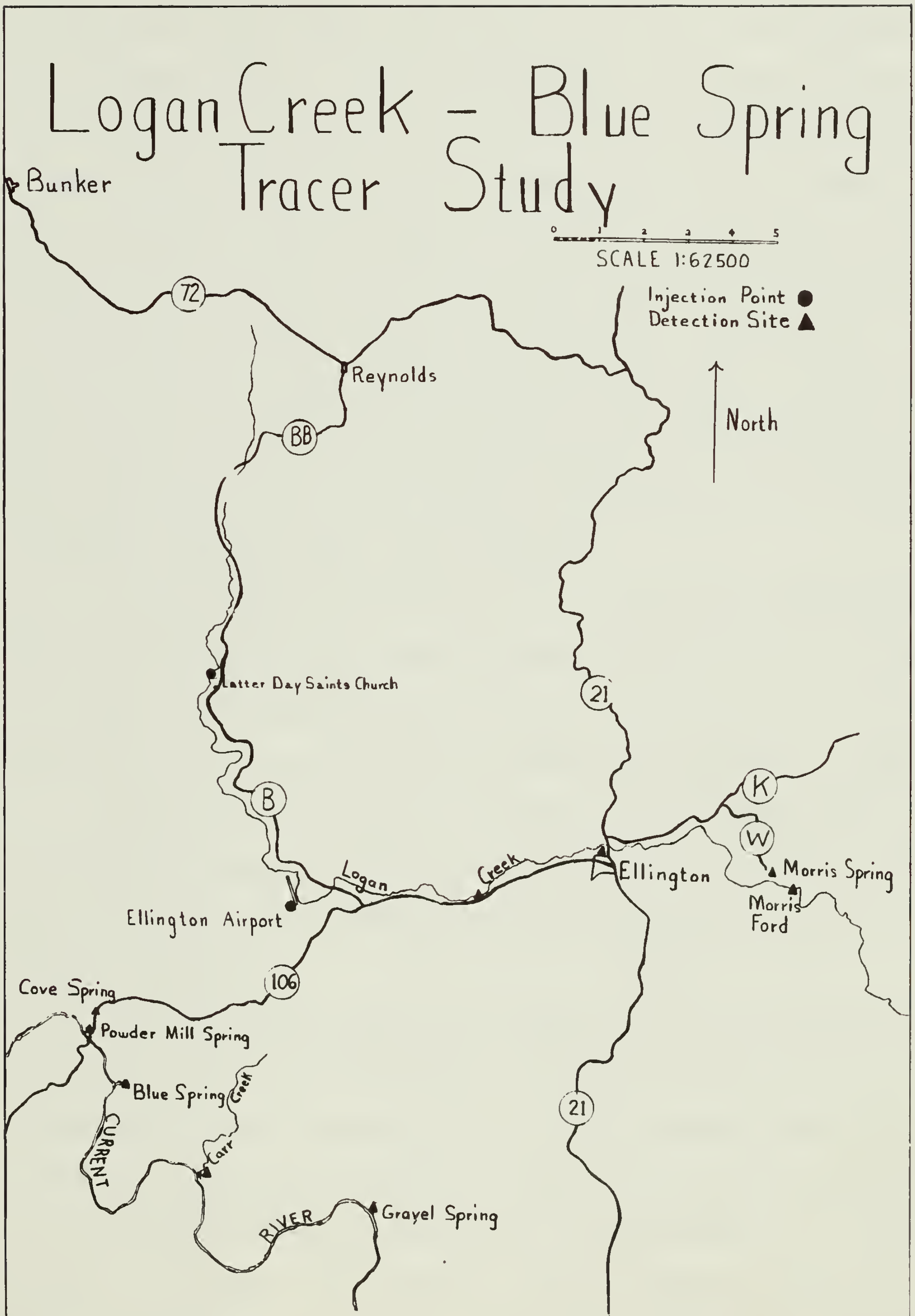



Figure 5-3, Location of Traces

to-18-foot rise in the Current River exceeded its 5-year flow. The unusual rise in Logan Creek caused water to back up into the sinkhole near the Ellington Airport. Because opportunities to trace that sink are so infrequent it was decided to pursue it even though the trace from upper Logan Creek was still in progress. Normally when a tracer study is done dye is injected at only one point. However, the availability of a fluorometer which had optical filters selectively sensitive to the wavelengths of rhodamine dye made it possible to do two traces simultaneously. Therefore, on April 21, rhodamine was injected in the airport sinkhole. At the time of injection, flood water from Logan Creek had backed up over the southern end of the airport and was flowing four to six feet deep in the narrow channel leading into the sinkhole.

As noted previously, both traces were successful. Analysis of the dye-collectors was done by project personnel using a U.S.G.S. fluorometer on loan to the Missouri Geological Survey. With the permission of the Missouri Survey some of the work was done in their laboratory in Rolla.

The fluorescein from upper Logan Creek arrived at Blue Spring within seven days after injection. It was strongly detectable up to fourteen days after injection and weakly detectable up to twenty days after injection (Figure 5-4).

The rhodamine from the airport sinkhole arrived at Blue Spring within twelve days. The initial travel time of the rhodamine may have been shorter but several attempts to reach the dye-collectors during the twelve-day interim were thwarted by high water. All of the rhodamine passed through the spring system during the twelve-day period of high water. No dye from either injection point was found by detectors at Powder Mill Spring, Cove Spring, Gravel Spring, Logan Creek near Dickens

SAMPLING INTERVALS, CHARCOAL DYE DETECTORS

Showing Intensity of Fluorescein (Fluor.) and Rhodamine (Rhod.) Detected

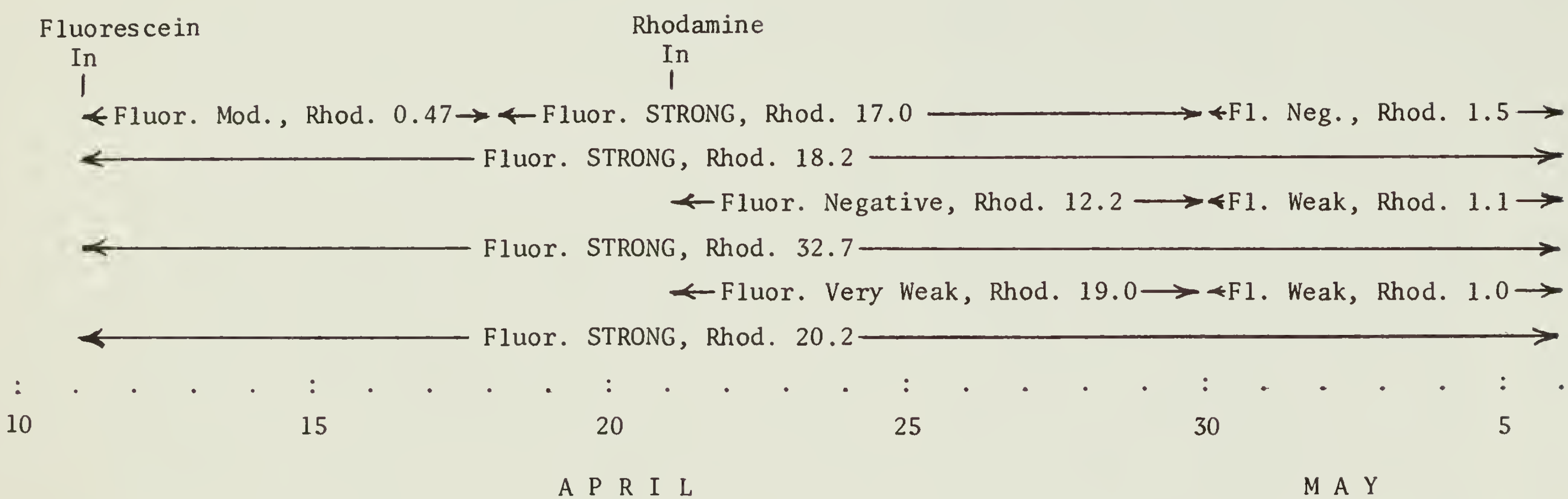



Figure 5-4

Valley, or Morris Spring. The detectors at Carr Creek and lower Logan Creek were destroyed by the flood.

The major importance of tracer studies in water resources investigations is that they provide knowledge of where subsurface water has been and where it is going. It is obvious that any determination of where sanitary sewage, storm sewage, and solid waste material should be disposed of must take into account the ultimate destination of any sinkhole, sink or sinking stream into which this material may drain. Adequate planning of treatment and disposal plants is essential and may be a major factor in Current River water quality for the coming decade. (A discussion of demographic factors affecting water quality is found in Section II, above.)

# Delineation of Groundwater Basin Divides for Big Spring

Thomas Aley

Big Spring is the largest spring in Missouri with an average annual flow of 428 cfs based upon a 49-year average through water year 1970 (U.S.G.S., 1971). In order to determine and delineate groundwater basin divides, it is necessary for us to have some understanding of the amount of area necessary to produce mean flows such as we observe.

Using the sum of flows at the Eleven Point River near Bardley and the Current River at Doniphan, I find that the mean annual yield for the area encompassing the Eleven Point and Current River basins is approximately 1.31 ft./year. This means that the water yield of the area equals a water depth of 1.31 feet over the entire area. This encompasses both surface and subsurface flow. 1.31 area feet of water equals 838 acre-feet/year/sq.mile.

Water yield in the karst lands of southern Missouri is composed both of surface and subsurface yield. For example, twenty years of water records from the Eleven Point River near Thomasville (through water year 1970) were examined. During this period the mean annual runoff was 3.26 area-inches. This is approximately 21% of the 1.31 area-feet estimated as total yield for the area; therefore, for the Eleven Point River at Thomasville approximately 21% of the mean annual yield is surface flow and the other 79% is subsurface flow.

Flow on Hurricane Creek, a 113 sq.mile drainage basin north of the Eleven Point River and south of Winona, has been measured for the last seven years by the Forest Service. Approximately 85% of the total

water yield of this basin is subsurface flow with the remaining 15% being surface flow leaving the basin and joining the Eleven Point River.

As a rough estimate of the amount of groundwater basin needed to produce observable flows at springs, I have made the assumption that for every one cfs of mean annual flow, you must have a groundwater basin of one square mile. One cfs/sq.mile equals 724 acre-feet/year. This equals 86% of the mean annual total water yield of the Current and Eleven Point River basins. Based on the data discussed above from the Eleven Point River near Thomasville and Hurricane Creek, the rule of thumb of one cfs indicating one square mile of drainage basin seems reasonable.

The mean flow of Big Spring is 428 cfs. Using the rule of thumb, this indicates a groundwater basin of approximately 428 square miles. This area is approximately equivalent to the area covered by two standard 15 minute U.S.G.S. topographic maps.

One problem in delineating groundwater basin divides is that some areas may be tributary to different streams or different springs depending on flow volumes. An example from Hurricane Creek will serve to illustrate the problem (see Figure 1). Water falling as precipitation in the upper portions of Hurricane Creek topographic basin provides subsurface recharge to Big Spring. During storm events, there is surface run-off from the upper portions of Hurricane Creek into the main surface stream channels in the area. A substantial amount of the groundwater recharge in the area occurs under the surface stream channels in what are locally called "losing streams."

Let's say we are concerned with precipitation falling in the vicinity of point A on Figure 1. The water falling in the vicinity of

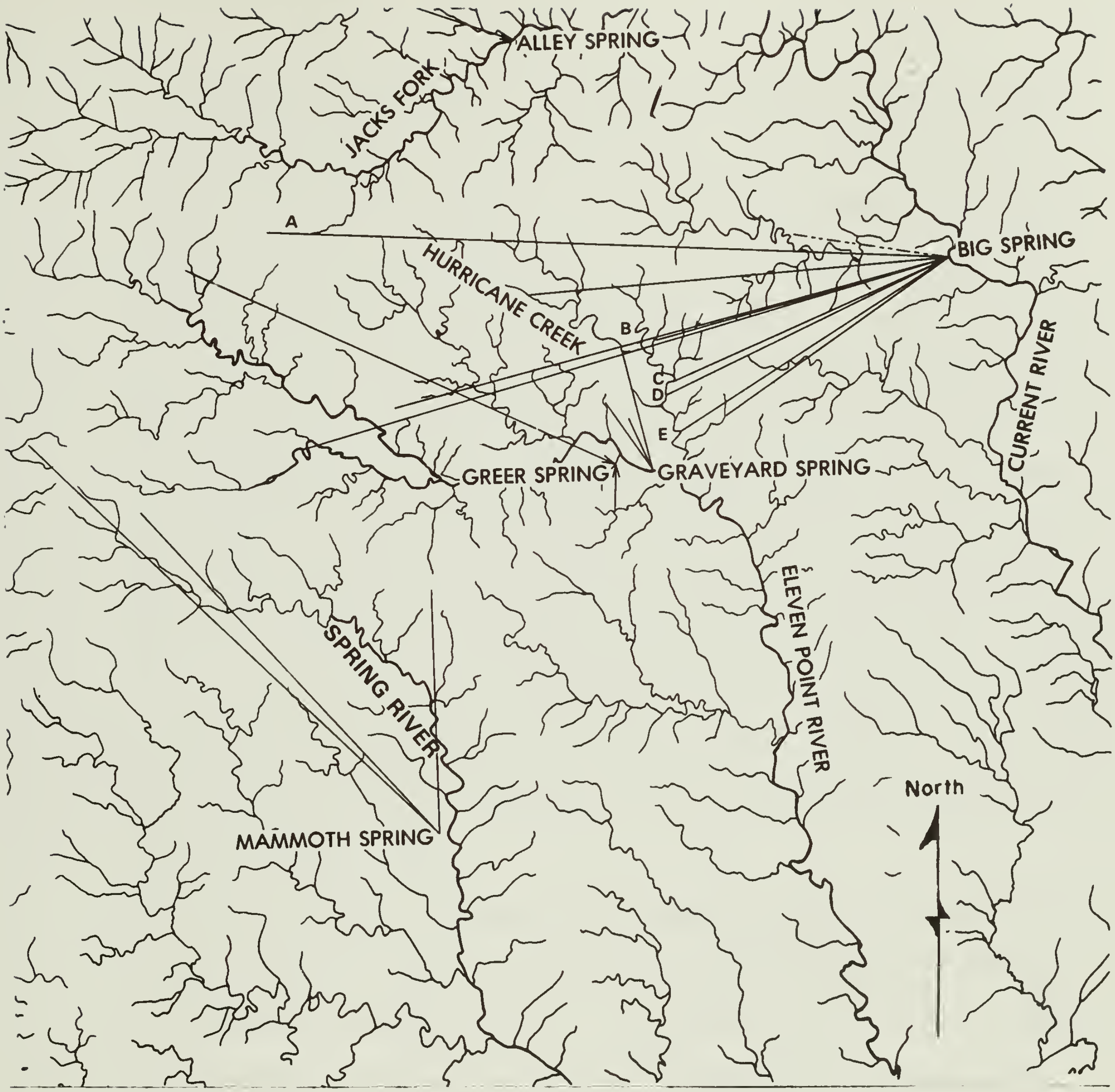



**Figure 1**

**Map showing surface drainage and groundwater traces in the vicinity of Hurricane Creek. Locations A, B, C, D and E are discussed in the text.**

**Key**

| | |
|---|---|
| ——→ | **Successful groundwater trace from point of injection to point of recovery.** |
| - - -→ | **Inferred trace from alcohol pollution reported by Bridge [1930].** |

Scale:

0 4 8 12 16 miles

point A may go underground and resurface at Big Spring, or it may continue down the channel of Hurricane Creek. If it continues down the channel, it may also go to Big Spring, or it may continue on down the channel to the vicinity of point B and serve as groundwater recharge for Graveyard Spring. Another possibility is that the water will continue beyond point B to the vicinity of point C, D, or E and again become groundwater recharge for Big Spring. Another possibility is that the water will successfully traverse the entire channel of Hurricane Creek and be yielded as surface flow to the Eleven Point River. The exact route followed by precipitation falling at some given point on the watershed is very much dependent upon the particular storm. Although we can delineate a generalized groundwater basin, we cannot delineate a basin which is always tributary to a given point. This is a major problem in dealing with the hydrology of karst areas and has been reported elsewhere (White, 1966).

Another matter which must be considered in delineation of groundwater recharge areas is the question of whether or not major rivers constitute groundwater barriers. In the case of Big Spring, it appears probable that almost all of the water yielded from the spring comes from the area lying to the west of the outlet and little, if any, comes from beneath the Current River. My extensive groundwater tracing program has shown that there is sufficient area lying to the west of Big Spring to account for the flow of that spring without needing to invoke any recharge areas lying east of the Current River.

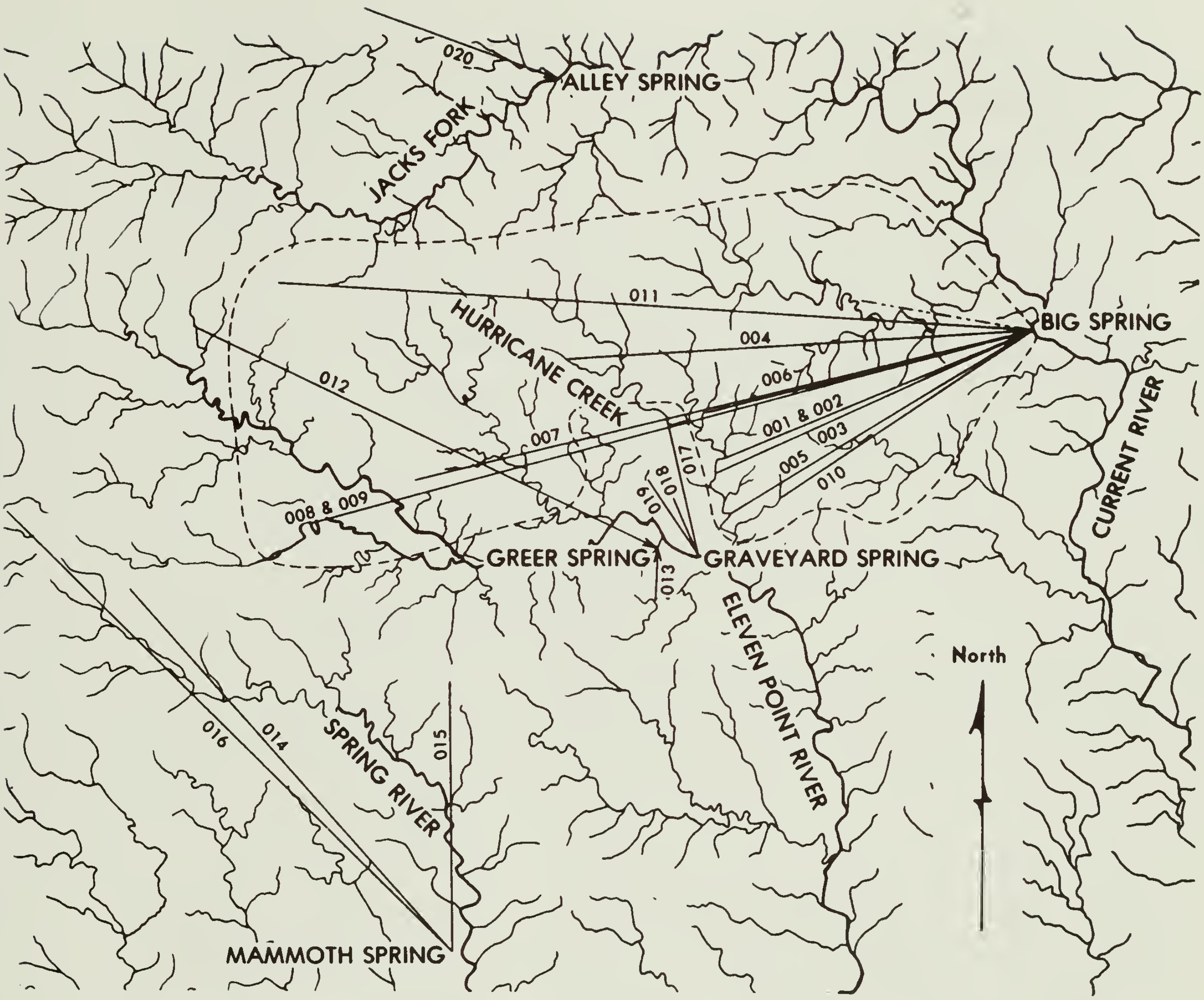
Work by Moneymaker (1969) in the karst lands of Tennessee indicates that solution conduits exist at substantial depth beneath major rivers. It is quite possible that some springs located on one side

of a river may receive recharge water from the area lying on the other side of the river. As an illustration of this in the Missouri karst lands, I conducted a successful dye trace from a disappearing stream in the lower end of McCormack Hollow, north of the Eleven Point River, to a spring discharging from the south bank of the Eleven Point River. This successful trace was in sections 24 and 25 of T25N R4W.

Figure 2 shows eleven successful groundwater traces to Big Spring which I have conducted over the last four years. Two of these were replications with stained Lycopodium spores. Bridge (1930) reports that Big Spring was once contaminated by isopropyl alcohol which was a by-product of the Mid-Continent Iron Company located near Midco. This "trace" is shown on Figure 2 by a broken line.

The straight lines on Figure 2 extend from the point of dye (or Lycopodium) injection to the point of recovery. It should be remembered that this is a graphical representation as groundwater flow is not in straight lines. You will note that there are come intersections in the straight lines headed to Big Spring with those headed toward Graveyard and Greer Springs. This does not indicate that the waters somehow cross underground. The lines cross merely because of the graphical approach used in displaying the groundwater tracings.

The dotted line shown in Figure 2 is an approximation of the groundwater recharge area for Big Spring. The location of the line is based upon all groundwater tracing work conducted in the area plus extensive field observation. In most areas the line is within two or three miles of being correct. The groundwater recharge line is least precise on the north side of the recharge area and on the south-east corner of the recharge area.




Key

⟶ Successful groundwater trace from point of injection to point of recovery

— - - — - -➤ Inferred trace from alcohol pollution reported by Bridge (1930).

Numbers refer to reference numbers of the traces involved.

Scale

4 0 4 8 12 16 miles

Figure 5-2, Successful groundwater traces to Big Spring,

Figure 2 provides us with a good general picture of where the recharge area for Big Spring is located. Our tracing work indicates that the towns of Mountain View, Birch Tree, Winona, and Fremont are all within the recharge area of Big Spring. Much of Hurricane Creek, where extensive groundwater studies have been conducted, is tributary to Big Spring. Note that in the upland area, somewhat west of Mountain View, there is a groundwater divide between Big Spring and Greer Spring. Future investigative work in conjunction with Greer Spring will probably help define this boundary.

Groundwater Tracing to Big Spring

A total of eleven successful groundwater traces have been conducted to Big Spring. Data from these traces is summarized in Table 1; the traces are shown on the map in Figure 2.

Several of the traces summarized in Table 1 are of particular importance. The Dowler Sink Trace (reference number 004) is from a subsiding sinkhole which receives surface runoff from nearby pasture land through a constructed channel. The potential problems inherent in this type of situation will be discussed in detail in connection with the Summersville Trace to Alley Spring, and will not be repeated here.

The Middle Fork Traces (reference numbers 008 and 009) represent the longest underground water traces known to have been conducted in the world. Straight-line travel distance for these traces is 39.5 miles. These traces indicate that a deterioration in water quality in the area lying north of West Plains could adversely affect Big Spring, in that this deterioration in water quality would affect the quality of water entering the Big Spring drainage system near Fanchon. Trace

009 is particularly important because it shows that suspended materials of up to 33 microns in diameter can be transported by the groundwater system to Big Spring.

The Mountain View Trace (reference number 011) is important because the point of dye injection is immediately downstream of the Mountain View sewage lagoon. This area is a significant source of contamination for Big Spring.

Groundwater Tracing to Alley Spring

Alley Spring has a mean annual flow of 124 cfs (U.S.G.S, 1971). Using the rule of thumb that 1 cfs of mean annual flow equals 1 square mile of drainage basin, the drainage basin for Alley Spring should be approximately 124 square miles. The recharge area for Alley Spring must be bounded by recharge areas for Round Spring on the Current River and Blue Springs on the Jacks Fork. The mean flow of Round Spring is 40 cfs (U.S.G.S., 1971). Blue Spring (Jacks Fork) has not been measured sufficiently often for us to have a very good idea of its mean flow. As a very rough approximation, the mean flow of this spring is probably on the order of 10 cfs, thus indicating a recharge area of 10 square miles.

Bridge (1930) reports that Alley Spring once went dry for about 12 hours, and then suddenly resumed flow. For several days the water was quite muddy. About the same time, a large sinkhole developed about 15 miles northwest of the spring. Beckman and Hinchey (1944) repeat the Bridge (1930) report, and conclude that the recharge area must lie to the west and north of the spring.

Figure 3 is an approximate delineation of the recharge areas for Alley and Round Springs. The delineations are only approximations; we simply do not have the quantity and quality of data for these springs that we do for Big Spring. The boundaries are based on field reconnaissance and a consideration of available hydrologic and geologic data.

Figure 3 shows a successful groundwater trace to Alley Spring from approximately 2 miles northeast of Summersville. This trace, which will be discussed in detail below, provides confirmation for the groundwater recharge boundary shown in Figure 3.

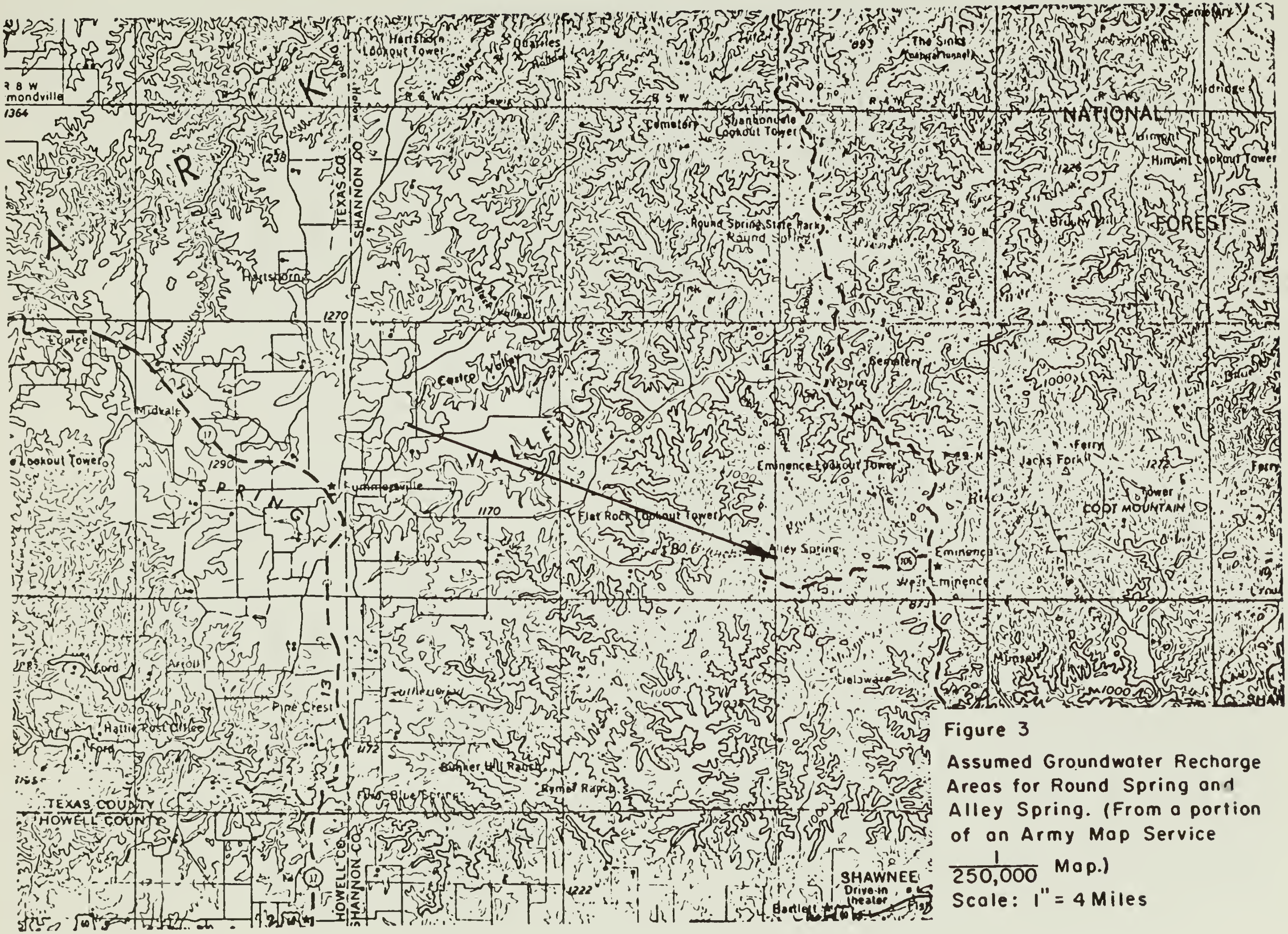



Figure 3

Assumed Groundwater Recharge Areas for Round Spring and Alley Spring. (From a portion of an Army Map Service $\frac{1}{250,000}$ Map.)

Scale: 1" = 4 Miles

The Summersville Trace originated on the Horton Davis farm, in the center of the SE½ NW¼ Sect. 8, T29N, R6W, Shannon County, Missouri. Ten pounds of fluorescein dye were injected on November 1, 1972 at 2:25 p.m. in a sinkhole 30 to 40 feet deep into which surface runoff from pasture land has been diverted. At the time of injection, it was raining heavily and the sinkhole was ponded approximately 15 feet deep. The estimated flow disappearing in the sinkhole was approximately 2 cfs.

Dye from the Summersville Trace appeared at Alley Spring between Nov. 1 and Nov. 9, 1972; I estimate that the first dye arrived on or about Nov. 5, 1972. This was four days after the injection. The straight-line travel distance between point of injection and point of recovery is 11.0 miles; assuming a four day travel time, the mean groundwater velocity for the eleven mile straight line distance equals 600 feet per hour.

The elevation of the injection site is 1140 feet; the elevation of Alley Spring is approximately 665 feet. This equals a mean gradient of 8.2 feet per 1,000 feet of straight line travel distance.

The Summersville Trace is important for three reasons. First, it is the first successful goundwater trace to Alley Spring, and provides some confirmation for the proposed delineation of the recharge area of this spring. Secondly, the trace is from near Summersville, and indicates that the Summersville area is a contributor to the flow of Alley Spring. Many of the spring contamination problems in the Ozark Highlands are related to communities; Summersville is the largest community in the upland area between the Current and Jacks Fork Rivers. Our tracing indicates that if groundwater contamination problems arise from Summersville, it is Alley Spring which will be affected.

The third reason the Summersville Trace is important is that it shows very rapid groundwater movement from a sinkhole (which has been modified by man) to a major spring. A travel time of four days, or for that matter even eight days, is very rapid. This sort of groundwater system is very susceptible to contamination; it provides little detention time and certainly little effective filtration. The runoff water entering the Horton Davis sinkhole receives little filtration before it reappears at Alley Spring. Should the diversion of pastureland runoff water into sinkholes become a common practice in the recharge areas for the local spring, groundwater deterioration is bound to occur. Not only must the land managers charged with the management of the public springs and rivers realize the problems inherent in the use of sinkholes for the disposal of runoff water, but the residents of the area must also understand the consequences of this sort of land practice.

# Characterization of the Flow Regimen of Big Spring

Thomas Aley

## Introduction

Over a billion gallons of water gushes daily from the springs of the Missouri Ozarks. The purpose of this section is to characterize the regimen, or flow characteristics, of a typical Missouri karst spring. Because of work by the U.S. Forest Service on the Hurricane Creek Barometer Watershed and adjacent areas, we have a substantial amount of unique and useful data available on Big Spring which is not available for other springs. This fact, plus over 50 years of flow data from the spring, give us a wealth of basic information on Big Spring, and as a result, we have selected this spring for our characterization.

Earlier I noted that Big Spring has a mean flow of 428 cfs, and that we could anticipate a recharge basin of about 428 square miles. Consider for a moment a groundwater system capable of drainage of about 85% of the total yield from an area of over 400 square miles, and it is obvious that we are dealing with a large scale, well connected drainage system.

## Flood Flows

Big Spring responds rapidly to precipitation. Peak flow at the spring generally occurs on the same day or the following day as flood peaks on the Current River at Van Buren. Table 2 shows ten recent storm periods, and records the date of peak flow at both Big Spring and the Current River at Van Buren. The rapid response of Big Spring to precipitation is typical of most of the karst springs in the Ozarks.

There are two possible explanations for the rapid response of the springs to precipitation. First, the flood water discharging from the spring could be the same water which only shortly before fell on the land as precipitation. The second possibility is that water discharging from the spring has been forced out by the pressure of water added in the upland area. The second case would follow the basic mechanism of artesian aquifers.

Table 2

Dates of Peak Flows at Big Spring and the Current River at Van Buren for Ten Storms from 1968 to 1971

| Birch Tree Precipitation | | | Date of Peak Flow | |
|---|---|---|---|---|
| | | | Big Spring | Current R. at V. Buren |
| Date | Quantity (inches) | | | |
| Nov. 1 | 1.07 | | | |
| Nov. 2 | 1.03 | | | |
| Nov. 3 | 1.15 | ............ | Nov. 3, 1968 | Nov. 2, 1968 |
| Nov. 26 | 0.40 | | | |
| Nov. 27 | 0.94 | | | |
| Nov. 28 | 0.75 | ............ | Nov. 28, 1968 | Nov. 27, 1968 |
| Dec. 27 | 2.43 | | | |
| Dec. 28 | 0.23 | ............ | Dec. 27, 1968 | Dec. 27, 1968 |
| Jan. 29 | 2.35 | | Jan. 31, 1969 | Jan. 30, 1969 |
| March 23 | 2.45 | | | |
| March 24 | 0.38 | ............ | March 25, 1969 | March 25, 1969 |
| April 9 | 1.53 | | April 9, 1969 | April 10, 1969 |
| March 1 | 0.20 | | | |
| March 2 | 0.27 | | | |
| March 3 | 0.26 | ............ | March 3, 1970 | March 3, 1970 |
| March 4 | 0.03 | | | |
| April 17 | 0.13 | | | |
| April 18 | 1.46 | | | |
| April 19 | 1.87 | ............ | April 20, 1970 | April 19, 1970 |
| April 30 | 3.47 | | May 1, 1970 | May 1, 1970 |
| Aug. 6 | 0.30 | | | |
| Aug. 7 | 0.22 | | | |
| Aug. 8 | 0.88 | | | |
| Aug. 9 | 3.53 | ............ | Aug. 9, 1970 | Aug. 9, 1970 |
| Oct. 12 | 0.20 | | | |
| Oct. 13 | 3.76 | ............ | Oct. 14, 1970 | Oct. 14, 1970 |
| Oct. 26 | 0.54 | | | |
| Oct. 27 | 0.87 | | | |
| Oct. 28 | 0.37 | ............ | Oct. 28, 1970 | Oct. 28, 1970 |
| Jan. 3 | 0.86 | | Jan. 4, 1971 | Jan. 5, 1971 |
| Jan. 13 | 1.28 | | Jan. 15, 1971 | Jan. 15, 1971 |
| Feb. 21 | 0.82 | | Feb. 22, 1971 | Feb. 23, 1971 |
| Feb. 22 | 0.04 | | | |

Note: All storms selected produced flow increases at Big Spring in excess of 100 cubic feet second/per day.

There are three lines of evidence indicating that flood water discharging from Big Spring is primarily the same water which only shortly before fell as precipitation.

1. Flood flows from springs are often turbid. One would not expect a substantial increase in water turbidity if the artesian mechanism operated at the spring. Figure 4 is a graph showing the relationship of water turbidity to flow rate at Greer Spring. The graph is based upon 58 turbidity measurements made at 16 day intervals for 22 months, and then once a month for the remaining 18 months. Measurements were made between July 24, 1969 and November 15, 1972. The behavior of Greer Spring is similar to the behavior of Big Spring, and it is logical to assume that general relationships of this sort characterize all major springs in the Ozarks.

Figure 4 indicates an exponential rise in turbidity as flow of Greer Spring increases. This is similar to the behavior of a surface stream, and is an indication that the large springs of the Ozarks operate primarily as non-artesian systems.

2. Water discharging from springs during flood flows has a lower electrical conductivity than water discharging from springs immediately before the storm period. This conclusion is based on several hundred electrical conductivity measurements made at a number of springs in the Ozarks, and is confirmed by systematically collected data from Greer Spring (see Figure 5).

Electrical conductivity is a measure of how well the water in question conducts electricity. The more dissolved material, the higher is the electrical conductivity. Furthermore, the longer water has been underground in the Ozarks, the more time it has to dissolve the calcareous bedrock, and the higher is the electrical conductivity. If the artesian condition existed, the electrical conductivity of storm flows from the springs should equal or exceed electrical conductivities measured prior to the storm flow. This is not the observed case.

3. Groundwater tracing work shows very rapid water movement. Travel rates from 300 to 600 feet per hour have generally been encountered

Fig. 4. Relationship of turbidity to flow rate at Greer Spring for the period from July 24, 1969 to Nov. 15, 1972. Data from U.S. Forest Service Eleven Point River Studies.

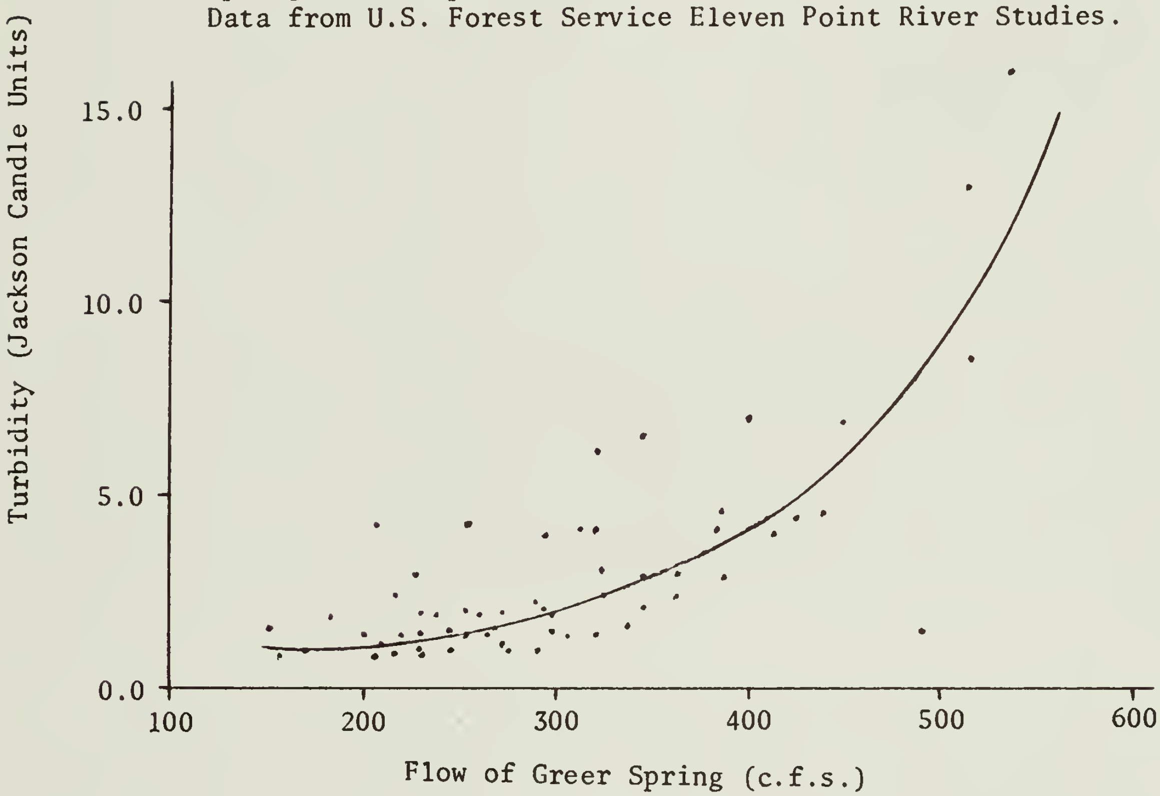
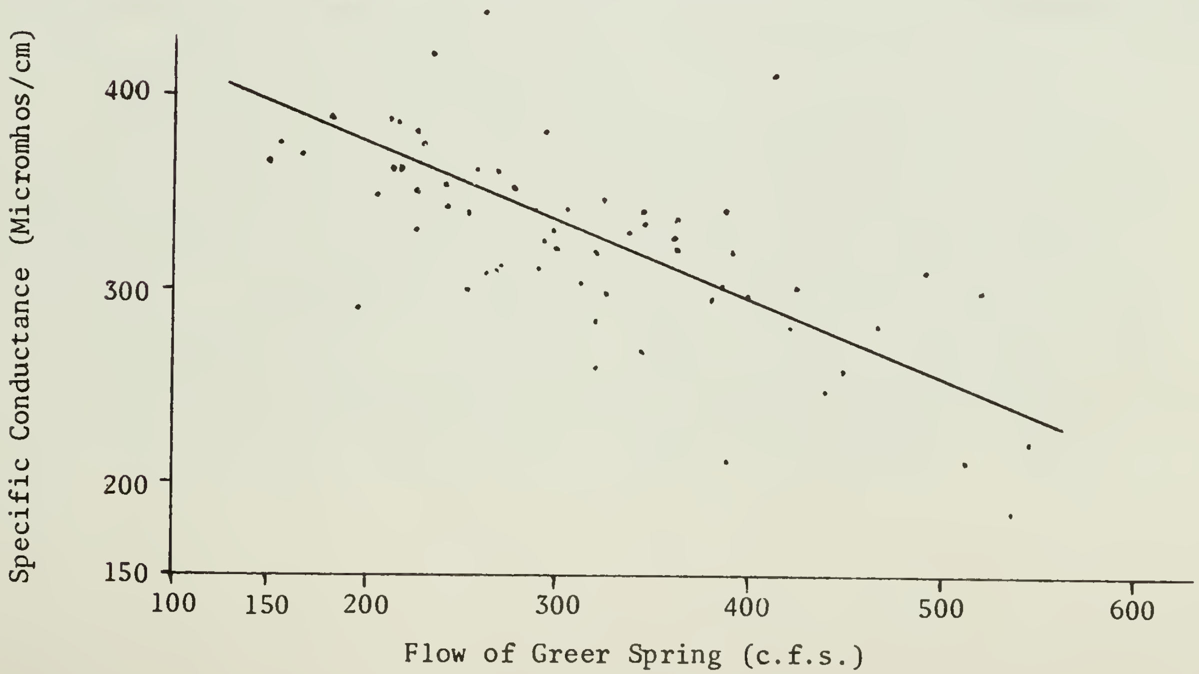



Fig. 5. Relationship of specific conductance to flow rate at Greer Spring for the period from May 5, 1969 to Nov. 15, 1972. Data from U.S. Forest Service Eleven Point River Studies.



in the tracing work I have done. The majority of our groundwater tracing work has occurred under low to moderate flow conditions. I would anticipate that much of the water moving through the karst aquifer travels at rates substantially greater than 300 to 600 feet per hour straight line distance. If we had rates of 1,000 feet per hour, this would equal five miles per day. This rate of travel would be adequate to produce the flood peaks observed at Big Spring.

The question of whether Big Spring functions as an artesian system or as a free flow system (as a surface stream does) is undoubtedly of interpretive interest, but the question is not particularly important for management purposes. What is important for management purposes is that water transport through the groundwater system is rapid. Travel rates of 300 to 600 feet per hour recorded for most of the traces to Big Spring are extremely rapid for groundwater systems. Even rates of 100 feet per hour are rapid.

Low Flows

Another feature of the water regimen of Big Spring, and the other large springs in the Ozarks, is that the springs have high sustained flows. The lowest flow ever recorded from Big Spring was 236 cfs on October 6, 1956; the highest flow of record was 1,300 cfs in June, 1928. Low flow is thus approximately 20% of peak flow. For comparison, the lowest flow of record for the Current River at Van Buren was 473 cfs on October 7 and 8, 1956; peak flow of record was 125,000 cfs on August 21, 1915. Low flow for the river is less than 0.4% of the peak flow.

Several factors are responsible for the ratio of low flow to high flow being much higher for Big Spring than for the Current River. In part, the ratio is affected because of the inability of some of the underground spring conduits to transport more than a finite quantity of water. The underground conduits have a fixed cross sectional area; surface streams do not. This helps explain the high ratio of low flow to high flow for Big Spring, but does not explain why the quantity of low flow is so well sustained. For example, the low flow of record

at Big Spring is 55% of the mean flow; the low flow for the Current River at Van Buren is only 26% of the mean flow at this station.

Two general factors can account for the sustained flow of Big Spring:

1. Ground water is protected from evaporation and transpiration. However, dye tracing which I have conducted shows that much of the water emerging from Big Spring enters from losing streams which are significantly affected by evapotranspiration.

2. Much of the deep residuum areas in the upland as well as numerous alluvial and residuum aquifers in the valleys are underdrained by the Big Spring drainage network. Release of water from the residuum and from the valley aquifers could continue for weeks or months even without additional surface precipitation. Figure 6 is a graph of the depth to water in Falling Spring well, an observation well on Hurricane Creek; this area is known to be underdrained by Big Spring. Note that the water level in the well continually falls throughout the summer. This valley aquifer is helping sustain flow at Big Spring. When major storms occur in the area, there is surface flow in Hurricane Creek and the valley aquifer is recharged.

Many of the surface valleys in the area tributary to Big Spring are broad and contain up to 50 or more feet of alluvial and residual material. The Falling Spring well penetrated 50 feet of this type material without encountering bedrock. A tremendous amount of water can be stored in these valley fills, and this water in storage is largely responsible for the high sustained flows noted at Big Spring.

Routes of Water Entry to the Groundwater System

A characterization of the flow regimen of Big Spring would be incomplete without some discussion of the nature of the routes for water entry into the groundwater system. These routes can be subdivided into two major classes; discrete recharge zones and diffuse recharge zones.

Discrete recharge zones are places where a significant quantity of water can enter the groundwater system through solution channels or

Depth to Water in Falling Spring Well, Hurricane Creek, 1968-1969

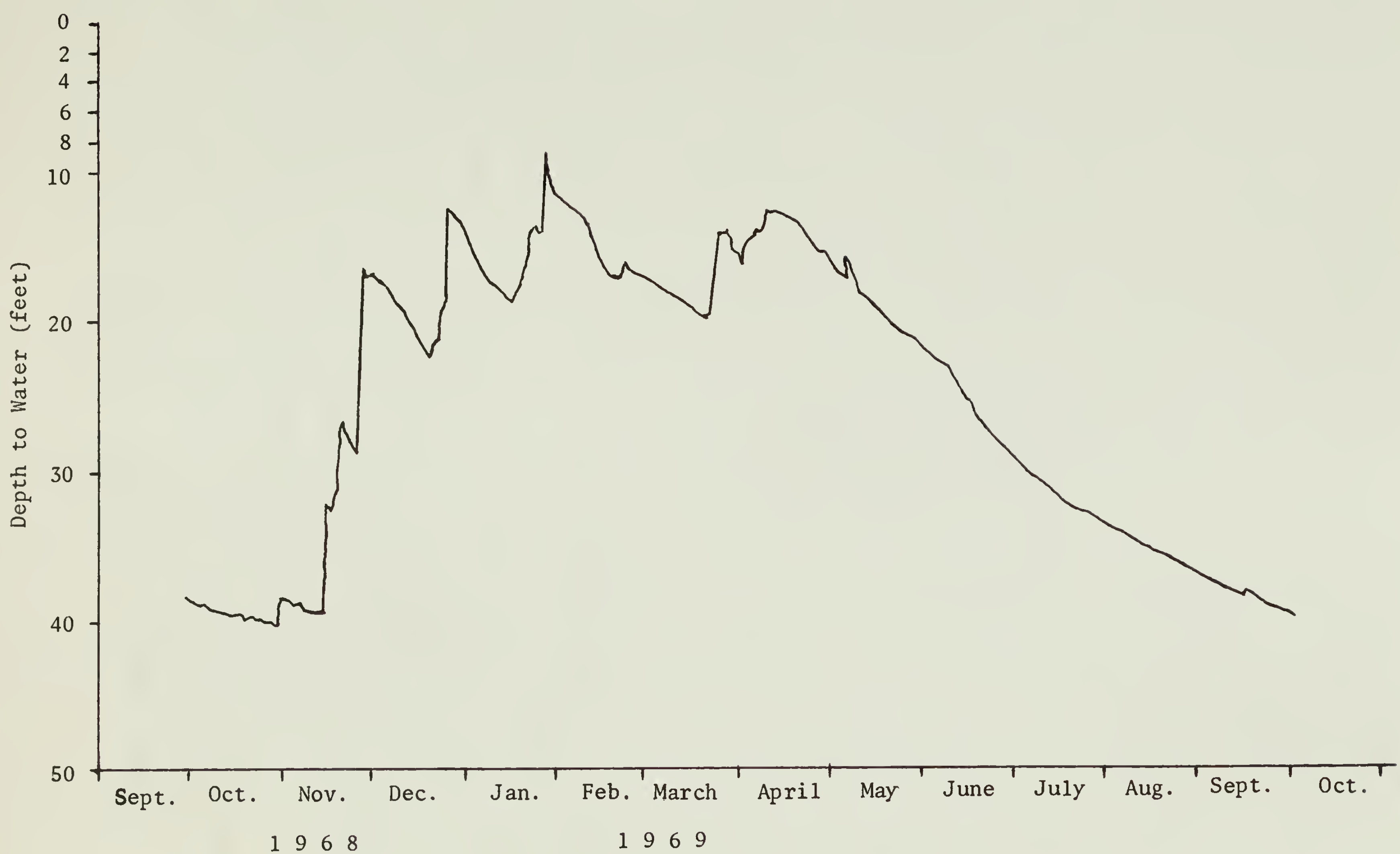



Figure 6. Depth to Water in Falling Spring Well

or other finite zones of limited extent. An example of a discrete recharge zone is a sinkhole which seldom if ever holds water. Water flowing into the sinkhole or precipitation falling into it enters the groundwater system through one or more discrete zones. The Dowler sinkhole (trace reference number 004) is a good example. Flows in excess of 20 cfs have been seen entering the sinkhole and disappearing from its bottom. Tracing this water with fluorescein dye demonstrated that the water reappeared at Big Spring.

Most losing stream segments are also examples of discrete recharge zones. There are many valley stream segments within the Big Spring recharge area which lose substantial quantities of water into the subsurface. With extensive field work it would be possible to map the locations of many of these, although the exact point where water ceases to flow on the surface is frequently dependent upon the quantity of the flow. Some of the losing stream segments are undoubtedly recharging valley aquifers (which will be discussed under diffuse recharge). It would be impossible to separate all losing stream segments into either discrete or diffuse recharge; probably the most convenient criteria for separation would be to label those losing stream segments where the water almost always disappears within two hundred feet of the same point as discrete recharge zones. With this criteria, those which disappeared through an area in excess of 200 feet long would be diffuse recharge zones.

Diffuse recharge zones are areas where water moves into the groundwater system in a dispersed fashion. Diffuse recharge zones should typically deliver water to the groundwater system more slowly than discrete recharge zones. Many of the valleys in the recharge area for Big Spring contain alluvial or residual material. These valley fills constitute significant diffuse recharge zones for Big Spring.

Much of the upland area within the Big Spring recharge zone is underlain by deep residuum. Residuum is the in-place weathering product of the bedrock, and in some areas may exceed 500 feet in depth (Aley et al., 1972). There is undoubtedly substantial diffuse groundwater recharge which occurs through the residuum.

Comments on the Nature of Conduits Feeding Big Spring

Big Spring is a well developed, well integrated network of solution channels which drain in excess of 400 square miles. It is presently impossible to enter the solution channels to describe or study them. Our evidence for characterizing the conduits must come from the hydrological behavior of the spring, with perhaps a little inferential evidence from air-filled caves in the region.

One of the most important characteristics of the solution channels feeding Big Spring is that they are very open systems. As we have shown in the discussion of flood flow, the spring system is very responsive to surface precipitation. Flow within the major conduits must frequently be turbulent, or else it would have been impossible for us to have traced *Lycopodium* spores to Big Spring from the Blowing Spring estavella on Hurricane Creek (trace reference number 002) or from the channel of the Middle Fork of the Eleven Point River (trace reference number 009). In undisturbed water in the laboratory, essentially all *Lycopodium* spores settle more repidly than 0.83 cm/hour (1/3 inch/hour). If the flow in the solution channels were laminar rather than turbulant, the spores would settle out of suspension and never be recovered at Big Spring.

Not only do the *Lycopodium* spores indicate that turbulent flow occurs in the conduits feeding Big Spring, but they also indicate that there is little effective filtration within the groundwater system. The mean diameter of *Lycopodium* spores is approximately 33 microns, which is 10 to 15 times larger than most bacteria. As an example, the size of *Salmonella typhosa*, the causative bacteria of typhoid fever, is 0.6 to 0.7 microns in diameter and 2.0 to 3.0 microns long. The size of *S. typhosa* is similar to most pathogenic bacteria. If the groundwater system is incapable of filtering out *Lycopodium* spores, the system certainly should not be expected to effectively filter out pathogenic bacteria.

## Dangers of Contamination and Pollution

Not only can springs be contaminated or polluted, but they have been. A classic case is the pollution of Big Spring in about 1920. Isopropyl alcohol was a waste by-product of the operations of the Mid Continent Iron Company, located in Midco Hollow (a tributary to Pike Creek). The alcohol was permitted to discharge into the ground near the plant; it reappeared in Big Spring.

Serious concern over this pollution originated at Doniphan, over 30 miles down the Current River below the confluence with Big Spring. Doniphan drew its drinking water from the Current River, and the residents noted an offensive taste in their water. Local informants say that Newt Cockran poled a john boat up the Current River to determine the source of the foul tasting water; the contaminated water all emerged from Big Spring. Apparently a law suit was filed by the City of Doniphan against Mid Continent Iron Company charging the company with water pollution. The suit was dropped when Mid Continent ceased operations.

Karst spring systems such as Big Spring are particularly subject to contamination and pollution. Contaminants move rapidly (as is well documented in the groundwater tracing data presented earlier). There is little effective filtration, indicated by our *Lycopodium* tracing and the invariable presence of coliform bacteria in water samples collected from Ozark springs. Furthermore, the groundwater system protects contaminants from sunlight and ultra violet radiation; UV sterilization is an important natural cleansing mechanism in surface streams.

There are five general classes of present and potential sources of water contamination and pollution. These are discussed below.

1. Towns and cities. The towns of Fremont, Winona, Birch Tree, and Mountain View are all within the recharge area for Big Spring. Domestic and industrial sewage presents a significant hazard. Sewage can deplete dissolved oxygen within portions of the groundwater system. Sewage also adds a substantial quantity of nutrients such as nitrates to the spring system. These nutrients increase algae and other aquatic

plant growth and can have a significant adverse impact on the appearance and esthetics of a spring. Visit Mammoth Spring, Arkansas and look at water clarity and the quantity of algae. Groundwater tracing in conjunction with the U.S. Forest Service's Eleven Point River studies has shown that the city of West Plains is within the Mammoth Spring discharge basin. Sewage from West Plains is significantly implicated in the nutrient enrichment of Mammoth Spring.

2. Feed lots, poultry houses, and similar sources of concentrated animal wastes. Problems presented by feed lots, etc. are similar to those presented by municipal sewage. As relates to the large springs in the Ozark, nitrate contamination is probably the most crucial problem. An an approximation, one cow produces about the same amount of fecal material as 16 people. A herd of 100 cows confined in a feed lot produces as much fecal material as a town of 1600 people.

A hundred cows in a feedlot present a much more significant water pollution hazard than a hundred cows on a grass pasture. Animals being pastured spread their fecal material widely, and the majority of it is rapidly bound up by surface vegetation. Conversely, wastes from a feedlot are localized, and exceed the ability of the local vegetation and soil to absorb and adsorb the nutrients. Consider the effects on spring water quality if runoff from feedlots is introduced underground through losing streams or sinkholes. Nutrients are not adsorbed or "filtered out" underground; once in the groundwater system they will reappear at a spring.

The number of animals in feedlots is increasing rapidly in southern Missouri. It is conceivable that feedlots may ultimately become the most significant source of spring water contamination in Missouri.

3. Leaky impoundments and poorly managed groundwater recharge operations. Leaky impoundments are frequently proposed for flood protection in the karst lands drained by large springs such as Big Spring. For example, over twenty impoundments have been proposed by the Soil Conservation Service for Pike Creek. Pike Creek is within the groundwater recharge area of Big Spring. None of the proposed impoundments would instead retard flood water and divert it underground.

The proposed flood control impoundments are in reality huge artificial groundwater recharge basins. In typical groundwater recharge operations, substantial attention is given to the maintenance and protection of groundwater quality. This is not the case with the recharge impoundments being proposed for the Ozarks.

The recharge impoundments would introduce storm water underground; storm flow is typically the poorest quality water flowing in the stream. Furthermore, recharge impoundments have been proposed downstream of such water quality hazards as city dumps, poultry houses, feed lots, and communities with inadequate sewage treatment facilities. Such impoundments could have serious effects on the water quality and esthetics of springs such as Big Spring. The problems of leaky impoundments are discussed at length in a monograph recently published by the Missouri Geological Survey and Water Resources (Aley, et al., 1972).

The diversion of surface runoff from fields, pasture, and conceivably feedlots into sinkholes presents problems similar to those created by leaky impoundments. The Summersville Trace to Alley Spring and the Dowler Trace to Big Spring were both from sinkholes which are being used as drainage for pastureland. If this type of agricultural practice becomes common, we should expect a deterioration in spring water quality.

4. Chemical spills. In late 1972 a spill of wood preservative chemicals at Cabool killed thousands of fish and did extensive environmental damage to the Big Piney River. A similar spill in the upland area recharging a spring would create similar damage to a spring and the river below it.

Chemical spills are generally restricted to highways, railroads, municipal areas, and industrial concerns. There are nearly 100 miles of primary state and federal highway within the Big Spring recharge area, plus thirty miles of railroad line. There is a large wood treatment plant at Winona, plus a large treated lumber yard near Fremont; both of these areas could be sources for toxic spills. Major gasoline spills

could occur at any service station within the groundwater recharge basin. Several thousand gallons of herbicide is stored by retailers and applicators within the recharge area; at times over 1,000 gallons has been in storage at one time at the Forest Service warehouse in Winona.

5. Use of pesticides. Pesticides, with the exception of herbicides, are not used in great quantities within the recharge area of Big Spring. Most insecticides are used in row crop agriculture, and there is very little of this type agriculture within the Big Spring recharge area. Herbicides on the other hand are used to convert woodland to pasture, or for forestry purposes. These uses introduce pesticides into the groundwater system. Major spray programs could produce floral and faunal damage at Big Spring. Mr. B. B. Morgan, operator of an aquatic plant farm at Morgan Spring and Blue Spring on the Eleven Point River, reported serious damage to some of his aquatic plants following aerial application of herbicide on the Pigman Ranch. Similar problems have been reported at limestone springs discharging from the Edwards Plateau in Texas.

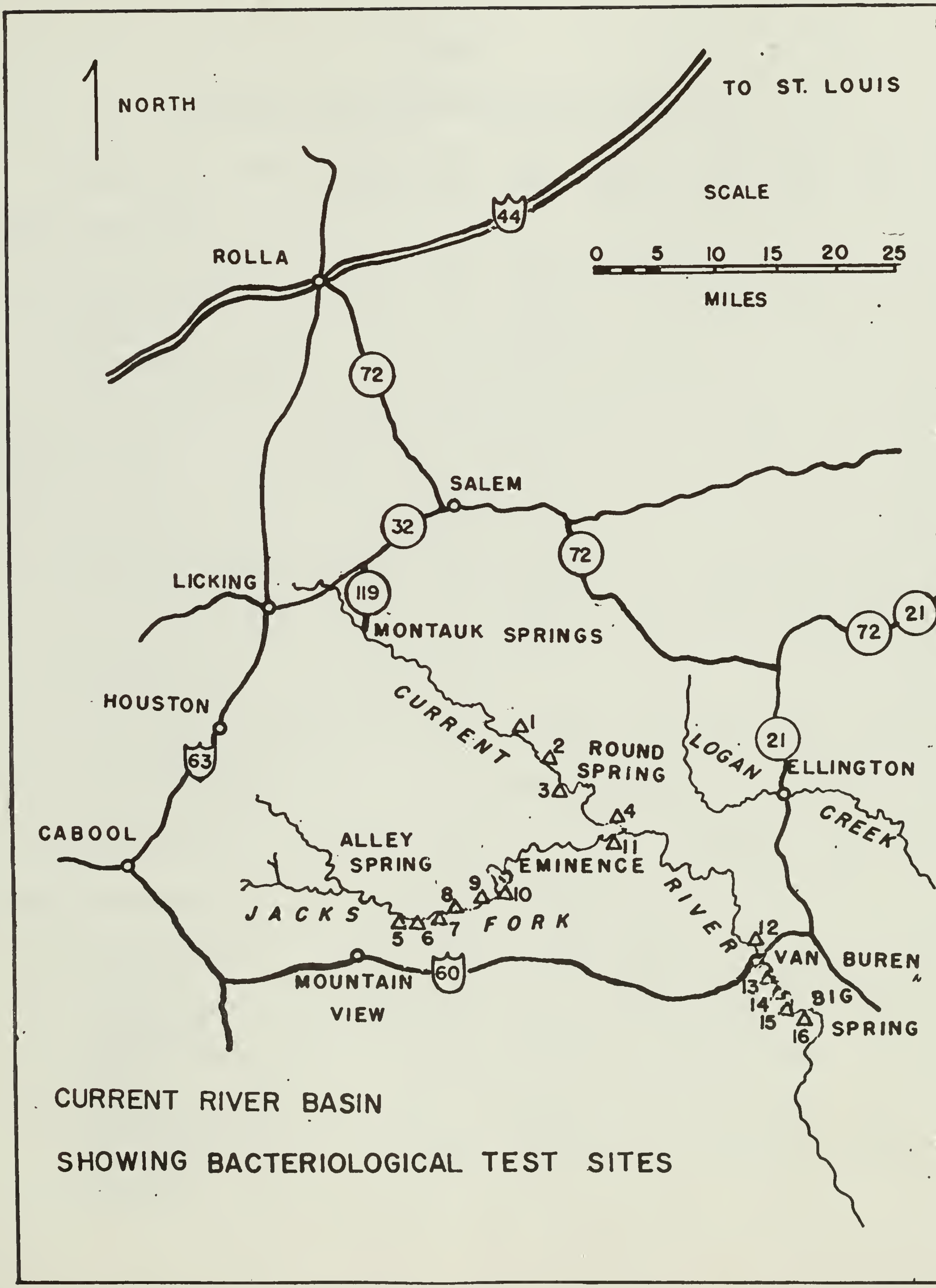
# SECTION VI

# BACTERIOLOGICAL STUDIES

## Three-Month Bacteriological Study

Water samples were collected at ten-day intervals at four sites on the upper Current, seven on Jacks Fork, and five on the lower Current (Figure 1). The ten-day sampling interval was chosen so that each day of the week would be included during the June-August test period. At each area except Eminence and Two Rivers, the sites were located above and below potential sources of pollution. Overall characterization and accessibility also were factors used in locating the sample sites. Not all of the sites were sampled throughout the entire period (see Table 1). To provide for both a wider reconnaissance and two additional local studies, the two stations at Two Rivers were relocated to Alley Spring and Big Spring, and an extra site was sampled once at Alley Spring. The results of the testing are listed in Table 2. All sample collection and analysis in the study was done by project personnel.

The first sampling run, on June 12, was done to determine the general range of values to be found in the rivers, and the dilutions or concentrations to be used in the analytical procedures. The results of this first run showed order of magnitude variations between separate samples taken from the same sites, as well as suspiciously high counts in a few samples. Above Alley Spring, fecal coliform counts were high while total coliform were low; at Two Rivers the Jacks Fork number of total coliform colonies was too numerous to count while the fecal coliforms were low. Because non-standard sample sizes (25 ml) were used in these analyses, the numerical results should be considered indicative but not conclusive.




CURRENT RIVER BASIN

SHOWING BACTERIOLOGICAL TEST SITES

Figure 6-1

Table 1

CURRENT RIVER BACTERIOLOGICAL SAMPLING

| Sample Sites | 1972 | 6-12 | 6-22 | 7-2 | 7-12 | 7-22 | 8-1 | 8-11 | 8-22 |
|---|---|---|---|---|---|---|---|---|---|
| | | Mon. | Thu. | Sun. | Wed. | Sat. | Tue. | Fri. | Tue. |
| **Upper Current River** | | | | | | | | | |
| 1. Above Sinking Creek | | c* | c,f,t | c,t* | | | | | |
| 2. At Round Spring Campground | | c,f | c,t | c,f,t | | | c,f,s | c,f | c,f,t |
| 3. Below Round Spring at Group Campground | | c,f | c,f,t | c,f,s,t | | | | | |
| 4. At Two Rivers | | c,f | c,f,t | | | | | | |
| **Jacks Fork River** | | | | | | | | | |
| 5. 2 mi. above Alley Spring Branch | | | c,f,t | | | | | | |
| 6. Swampy Campground above Alley Spring | | c,f | c,f,t | c,f,s,t | s | c,f,d | c,f,s | c,f | c,f,t |
| 7. 0.2 mi. above Alley Spring Branch | | | c | c,f,s,t | s | c,f,s | c,f,s | c,f | c,f,t |
| 8. 0.2 below Alley Spring Branch | | c,f | c,f,t | | | | | | |
| 9. Center channel below Eminence Lagoon | | c,f | c,f,t | c,f,s,t | s | c,f,s | c,f,s | c,f | c,f,t |
| 10. Right side below Eminence Lagoon | | | c,f | c,f,s,t | s | c,f,s | c,f,s | c,f | c,f,t |
| 11. At Two Rivers | | c,f | c,f,t | | | | | | |
| **Lower Current River** | | | | | | | | | |
| 12. Deer Run above Van Buren | | c,f | c,f,t | c,f,s,t | s | c,f,s | c,f,s | c,f | c,f,t |
| 13. Garden of Eden Campground | | c,f | c,f,t | | s | c,f,s | c,f | c,f | c,f,t |
| 14. Above Big Spring Branch | | | c,f,t | | s | c,f,s | c,f,s | c,f | c,f,t |
| 15. Big Spring Branch above bridge | | | | c,f,s,t | s | c,f,s | c,f,s | c,f | c,f,t |
| 16. Chubb Hollow below Big Spring | | c,f | c,f,t | c,f,s,t | s | c,f,s | c,f,s | c,f | c,f,t |

*c = total coliform, f = fecal coliform, s = fecal streptococci, t = temperature and specific conductance

Table 2

Summary of Water Quality Test Results

| Test Dates | 1972 | 6-12 | 6-22 | 7-2 | 7-12 | 7-22 | 8-1 | 8-11 | 8-22 |
|---|---|---|---|---|---|---|---|---|---|
| Sample Sites on Upper Current River | | Results/Number of Samples | | | | | | | |
| 1. 800 ft. above | (c) | TNTC/1 | 100/3* | 45/3 | | | | | |
| confluence with | (f) | | 16/1* | 0/1 | | | | | |
| Sinking Creek | (t) | | 64 | 66 | | | | | |
| | (sc) | | 300 | 305 | | | | | |
| 2. At Round Spring | (c) | 75/1 | 130/2 | 75/3 | | | 220/2 | 110/2 | 54/2 |
| Campground | (f) | 15/1 | | 11/1 | | | 34/2 | 20/2 | 34/2 |
| boat ramp | (s) | | | | | | 31/1 | | |
| | (t) | | 66 | 66 | | | | | 72 |
| | (sc) | | 300 | 320 | | | | | |
| 3. Below Round | (c) | 50/2 | 100/3 | 121/4 | | | | | |
| Spring, at Group | (f) | 12/1 | 1/1 | 6/2 | | | | | |
| Campground | (s) | | | 380/2 | | | | | |
| | (t) | | 66 | 65 | | | | | |
| | (sc) | | 240 | 315 | | | | | |
| 4. At Two Rivers, | (c) | 45/1 | 120/2 | | | | | | |
| 200 ft. above | (f) | 46/1 | 16/1 | | | | | | |
| Jacks Fork | (t) | | 68 | | | | | | |
| | (sc) | | 305 | | | | | | |
| Jacks Fork River | | | | | | | | | |
| 5. 2 mi. above | (c) | | 140/3 | | | | | | |
| Alley Spring | (f) | | 15/1 | | | | | | |
| Branch | (t) | | 73 | | | | | | |
| | (s) | | 320 | | | | | | |
| 6. Above Swampy | (c) | 15/2 | 140/5 | 8/3 | | 300/2 | 420/2 | 130/2 | 14/2 |
| Campground | (f) | 300/1 | 13/1 | 4/2 | | 18/2 | 24/2 | 21/2 | 35/2 |
| 1 mi. above | (s) | | | 47/2 | 13/4 | 48/1 | 26/1 | | |
| Alley Spring | (t) | | 74 | 74 | | | | | 86 |
| Branch | (sc) | | 320 | 330 | | | | | |

c = total coliform, f = fecal coliform, s = fecal streptococci, all in colonies per 100 milliliters

t = temperature in degrees fahrenheit, sc = specific conductance in micromohos

*First number is average value, second is number of samples

Table 2 (cont.)

| Test Dates | 1972 | 6-12 | 6-22 | 7-2 | 7-12 | 7-22 | 8-1 | 8-11 | 8-22 |
|---|---|---|---|---|---|---|---|---|---|
| | | Results/Number of Samples | | | | | | | |
| 7. At highway | (c) | | 145/2 | 49/4 | | 40/2 | 320/2 | 106/2 | 30/2 |
| bridge, ¼ mi. | (f) | | | 5/4 | | 16/2 | 18/2 | 16/2 | 10/2 |
| above Alley | (s) | | | 33/2 | 4/4 | 80/1 | 32/1 | | |
| Spring Branch | (t) | | | 74 | | | | | 84 |
| | (sc) | | | 320 | | | | | |
| 8. 0.2 mi. below | (c) | neg/1 | 210/3 | | | | | | |
| Alley Spring | (f) | 7/1 | 24/1 | | | | | | |
| Branch | (t) | | 64 | | | | | | |
| | (s) | | 280 | | | | | | |
| 9. Center channel | (c) | 20/2 | 220/3 | 120/3 | | 420/2 | 280/2 | 82/2 | 0/2 |
| 200 ft. below | (f) | 15/1 | 9/1 | 30/3 | | 18/2 | 8/2 | 9/2 | 12/2 |
| Eminence | (s) | | | 120/2 | 9/4 | 92/1 | 96/1 | | |
| Lagoon | (t) | | 66 | 68 | | | | | 72 |
| | (sc) | | 300 | 300 | | | | | |
| 10. Near right bank, | (c) | | 190/5 | 86/2 | | 480/2 | 110/2 | 38/2 | 42/2 |
| 200 ft. below | (f) | | 43/1 | 53/4 | | 60/2 | 42/2 | 22/2 | 18/2 |
| Eminence | (s) | | | 160/2 | 3/4 | 2/1 | 30/1 | | |
| Lagoon | (t) | | | | | | | | 72 |
| | (sc) | | | | | | | | |
| 11. At Two Rivers, | (c) | TNTC/2 | 160/2 | | | | | | |
| 200 ft. above | (f) | 23/1 | 28/2 | | | | | | |
| confluence with | (t) | | 68 | | | | | | |
| Upper Current River | (s) | | 240 | | | | | | |
| <u>Lower Current River</u> | | | | | | | | | |
| 12. At Dear Run | (c) | 45/2 | 130/2 | 80/1 | | 340/2 | 180/2 | 64/2 | 8/2 |
| Campground | (f) | 4/1 | 10/2 | 4/4 | | 7/2 | 4/2 | 4/2 | 5/2 |
| above Van Buren | (s) | | | 30/2 | 9/4 | 18/1 | 20/1 | | |
| | (t) | | 72 | 74 | | | | | 82 |
| | (sc) | | 300 | 320 | | | | | |
| 13. At Garden of | (c) | 40/2 | 200/2 | | | 470/2 | 290/2 | 70/2 | 4/2 |
| Eden C. G. | (f) | 7/1 | 15/2 | | | 18/2 | 40/2 | 24/2 | 8/2 |
| below Van | (s) | | | | 29/4 | 109/1 | | | |
| Buren | (t) | | 73 | 74 | | | | | 80 |
| | (sc) | | 295 | 315 | | | | | |

Table 2 (cont.)

| | Test Dates | 1972 | 6-12 | 6-22 | 7-2 | 7-12 | 7-22 | 8-1 | 8-11 | 8-22 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Results/Number of Samples | | | | | | | |
| 14. | 0.2 mi. above | (c) | | 150/1 | | | 520/2 | 270/2 | 66/2 | 15/2 |
| | confluence with | (f) | | 26/2 | | | 36/2 | 14/2 | 10/2 | 20/2 |
| | Big Spring | (s) | | | | 8/4 | 30/1 | 82/1 | | |
| | Branch | (t) | | 72 | 75 | | | | | 82 |
| | | (sc) | | 300 | 240 | | | | | |
| 15. | Big Spring | (c) | | | 88/4 | | 160/2 | 40/2 | 16/2 | 2/2 |
| | Branch 50 ft. | (f) | | | 3/4 | | 64/2 | 13/2 | 8/2 | 8/2 |
| | above bridge | (s) | | | 18/2 | 35/4 | 25/1 | 73/1 | | |
| | | (t) | | | 58 | | | | | 58 |
| | | (sc) | | | 315 | | | | | |
| 16. | At Chubb | (c) | 70/1 | TNTC/1 | 36/1 | | 810/2 | 230/2 | 100/2 | 30/2 |
| | Hollow Camp- | (f) | 5/1 | 32/2 | 4/1 | | 44/2 | 14/2 | 14/2 | 10/2 |
| | ground below | (s) | | | 12/1 | 7/4 | 28/1 | 37/1 | | |
| | Big Spring | (t) | | 64 | 65 | | | | | 70 |
| | | (sc) | | 300 | 320 | | | | | |

Results of the June 22 sampling were more consistent and generally higher. No exceptionally high values were found. Most of the total coliform samples were in the 100 to 200 counts per 100 ml range. Fecal coliform counts ranged from one to twenty percent of the total coliform values.

The July 2 samples were collected independently of those collected on the same day for the intensive study (see below). The volume of sample filtered in most cases was 25 ml. Because this led to fewer than 20 colonies per plate on two-thirds of the plates, the variation between plates from a single site is exaggerated when expressed as colonies per 100 ml. The total coliform counts ranged from 8 to 120 colonies per 100 milliliters, and the fecal coliform counts from 3 to 53.

The samples collected on July 12 were used to standardize the procedures for fecal streptococcal tests. This standardization test fully utilized the facilities, personnel and water samples available. Thus, only streptococcal tests were performed for this date. The results were much lower than had been anticipated on the basis of results from the July 2 tests.

The first four sets of tests, on June 12 through July 12, deliberately included a wide range of sample sites, test methods, and sample concentrations. This provided information about the range of conditions which are to be expected within the Riverway, and enabled selection of the optimum sample size for each method. It was found that for the total coliform test 25 milliliters of river water usually gave the desired number of colonies (20 to 100) per membrane filter. For the fecal coliform and fecal streptococcal tests, 100 milliliters usually produced the optimum concentration of colonies. Subsequently, these quantities were used in the second sampling series, from July 22 through August 22.

Results of the standardized series of tests, July 22 through August 22, show a general decline in total coliform count and a generally level value of fecal coliform count. The decline in total coliform count shows the gradual clearing of the rivers following the run-off producing rains of July 3 and 4 (see Short-Term Water Quality Study, below). The approximately level values of fecal coliform count indicates that the average "background" level for these rivers is in the 10 to 20 counts per 100 milliliter range, and that they return to this range within a few days after surface runoff occurs. Although all the observed counts have been reported to two significant digits, they should be assumed to have errors of up to 75 counts (or 25%) for values in the hundreds, and 20-30 counts (or 50%) for values between 5 and 100. (See Methods and Procedures, below).

A few of the results of this standardized series are noticeably different from the above general trends even considering the low precision of the methods. The total coliform sample on July 22 at the Alley Spring highway bridge on Jacks Fork is unusually low. Because the sample collected within the same half hour, one-half mile upstream above Swampy Campground, show an order of magnitude greater coliform presence it seems most likely that some pethogen either collected in the sample from the bridge site or introduced during the culturing of the sample reduced the number of colonies present. The fecal coliform counts on samples from the Current River at Deer Run Campground were consistently lower than those from elsewhere. No obvious reason for this was observed, other than that the long stretch of river from Two Rivers to Deer Run is generally remote from paved highways, difficult of access, and has very few houses on either bank. The August 1 sample from the Current River at Garden of Eden had a fecal streptococcal count three to four times higher than expected. A somewhat higher fecal

strep value was noted on the same day at the Current River site at Big Spring. This may indicate that on that day some pollution was introduced into the river between Deer Run and Garden of Eden, perhaps at Van Buren. A small surface stream flows from the embankment of Van Buren's waste stabilization lagoon east of town, westward through the town, directly to the Current River. Although no spills were observed during this study, a trench opened for repair work on a sanitary sewer was discharging some drainage into this stream channel.

Short-Term Water Quality Study

The short-term study of bacteriological and chemical factors was started on Friday, June 30, 1972. The sample collection and analysis was done under contract by personnel of the U.S. Geological Survey Water Resources Division, using a mobile field laboratory. The study had two broad purposes: to determine the effects if any of an increased number of visitors to the Riverway during a summer holiday week-end (Independence Day), and to provide data from a separate laboratory facility for comparison with those obtained by University of Missouri-Rolla personnel during the longer test. The "4th of July" was a Tuesday, and many employees also had Monday, the 3rd, off work thus giving a five-day holiday weekend. Unfortunately, rain which began on Sunday, July 2, and continued thru Monday, July 3, partially frustrated the first objective of this study. The gloomy wet weather reduced the number of visitors, and rain-induced surface runoff caused large increases in the number of bacteria in the rivers. This last factor fortunately was an unanticipated bonus, because it provided an excellent record of both the magnitude and variability of bacterial increases which can be expected from similar summer rains over the Riverway.

Because the same USGS field personnel who collected the samples had to do the analytical work, using a mobile field laboratory, the sampling had to be limited generally to ten locations. The sites used were the same as those of the longer-term study, plus two more closely-spaced at Big Spring to test for the effect, if any, of turbulent aeration immediately below the Spring. On the fourth day of the test one location was shifted to provide slightly wider coverage.

The results of this short term study do show some consistent trends (Table 3). The samples collected mid-day on the first day, Friday, show

TABLE 3

U. S. GEOLOGICAL SURVEY CURRENT RIVER STUDY

| Date and time | Total coliform (col/100 ml) | Fecal coliform (col/100 ml) | Fecal strep. (col/100 ml) | Temperature (°C) | Specific conductance (micromhos) | Dissolved oxygen (mg/l) | Percent saturation | pH | $HCO_3$ (mg/l) | $CO_3$ (mg/l) | Alkalinity (mg/l as $CaCO_3$) | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Current River below Round Spring Site 3 | | | | | | | | | | | | |
| 6-30-72 @ 1015 | 32 | 15 | 54 | 18.5 | 305 | 8.9 | 94 | 8.3 | 204 | 0 | 167 | |
| 7-1-72 @ 1430 | 36 | 5 | 43 | 21.0 | 305 | 9.2 | 102 | 8.4 | 204 | 0 | 167 | |
| 7-2-72 @ 1400 | 280 | 140 | 320 | 18.5 | 300 | 8.5 | 89 | 8.2 | 204 | 0 | 167 | Few light showers in area. |
| 7-3-72 @ 1230 | 110 | 17 | 93 | 19.5 | 305 | 9.4 | 101 | 8.3 | 206 | 0 | 169 | |
| 7-4-72 @ 1420 | 1700 | 34 | 310 | 17.0 | 300 | 9.9 | 102 | 8.0 | 196 | 0 | 161 | |
| Jacks Fork above Alley Spring (Camp Swampy) Site 6 | | | | | | | | | | | | |
| 6-30-72 @ 1135 | 13 | 13 | 73 | 25.0 | 320 | 11.1 | 134 | 8.2 | 224 | 0 | 184 | |
| 7-1-72 @ 1530 | 960 | 490 | 96 | 27.0 | 320 | 7.6 | 95 | 8.1 | 228 | 0 | 187 | |
| 7-2-72 @ 1530 | 350 | 42 | 160 | 24.0 | 310 | 7.6 | 89 | 7.8 | 220 | 0 | 180 | |
| 7-3-72 @ 1105 | 140 | 6 | 140 | 23.5 | 330 | 7.8 | 91 | 8.2 | 224 | 0 | 184 | |
| 7-4-72 @ 1300 | 800 | 34 | 300 | 22.0 | 310 | 9.1 | 103 | 7.9 | 212 | 0 | 174 | |
| Jacks Fork one-tenth mile above Alley Spring Site 7 | | | | | | | | | | | | |
| 7-3-72 @ 1130 | 210 | 44 | 280 | 24.0 | 325 | 7.9 | 93 | 8.1 | 228 | 0 | 187 | |
| 7-4-72 @ 1320 | 220 | 110 | 330 | 22.0 | 315 | 9.2 | 104 | 8.0 | 212 | 0 | 174 | |
| Jacks Fork below Eminence (center of stream below sewage lagoon) Site 9 | | | | | | | | | | | | |
| 6-30-72 @ 1340 | 64 | 15 | 26 | 21.0 | 300 | 9.7 | 108 | 8.3 | 208 | 0 | 171 | |
| 7-1-72 @ 1630 | 160 | 27 | 78 | 21.5 | 305 | 9.1 | 102 | 8.1 | 204 | 0 | 167 | |
| 7-2-72 @ 1640 | 100 | 32 | 160 | 20.5 | 300 | 9.2 | 102 | 8.1 | 202 | 0 | 166 | |
| 7-3-72 @ 0930 | 180 | 30 | 96 | 19.0 | 305 | -- | -- | 7.8 | 204 | 0 | 167 | |
| Jacks Fork below Eminence (right side of stream below sewage lagoon) Site 10 | | | | | | | | | | | | |
| 6-30-72 @ 1340 | 68 | 25 | 22 | 21.0 | 310 | 9.8 | 109 | 8.8 | 192 | 14 | 180 | |
| 7-1-72 @ 1630 | 84 | 40 | 280 | 21.5 | 300 | 8.4 | 94 | 8.1 | 204 | 0 | 167 | |
| 7-2-72 @ 1640 | 400 | 200 | 240 | 20.5 | 305 | 8.1 | 90 | 8.2 | 208 | 0 | 171 | |
| 7-3-72 @ 0930 | 320 | 48 | 170 | 19.0 | 310 | -- | -- | 8.1 | 208 | 0 | 171 | |
| 7-4-72 @ 1210 | 1400 | 280 | 860 | 18.5 | 310 | 8.0 | 84 | 7.9 | 204 | 0 | 167 | |
| Current River above Van Buren (KOA campground) Site 12 | | | | | | | | | | | | |
| 6-30-72 @ 1530 | 16 | 1 | 15 | 25.0 | 305 | 10.7 | 129 | 8.5 | 200 | 2 | 167 | |
| 7-1-72 @ 1150 | 92 | 3 | 19 | 24.0 | 305 | 7.2 | 85 | 8.4 | 204 | 2 | 171 | |
| 7-2-72 @ 1300 | 240 | 16 | 43 | 23.0 | 300 | 8.3 | 95 | 8.3 | 204 | 0 | 167 | |
| 7-3-72 @ 1730 | 86 | 30 | 140 | 23.5 | 290 | 8.5 | 99 | 8.2 | 196 | 0 | 161 | Sample collected during heavy rain -- possible surface runoff. |
| 7-4-72 @ 1045 | 2000 | 120 | 450 | 21.0 | 305 | 9.3 | 103 | 8.4 | 200 | 6 | 174 | Runoff yesterday. |

TABLE 3 -- continued

U. S. GEOLOGICAL SURVEY CURRENT RIVER STUDY

| Date and time | Total coliform (col/100 ml) | Fecal coliform (col/100 ml) | Fecal strep (col/100 ml) | Temperature (°C) | Specific conductance (micromhos) | Dissolved oxygen (mg/l) | Percent saturation | pH | $HCO_3$ (mg/l) | $CO_3$ (mg/l) | Alkalinity (mg/l as $CaCO_3$) | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Current River below Van Buren (Garden of Eden Camp) Site 13 | | | | | | | | | | | | |
| 6-30-72 @ 1620 | 14 | 1 | 14 | 25.0 | 300 | 11.6 | 140 | 8.5 | 200 | 4 | 171 | Collected duplicate sample. |
| 6-30-72 @ 1620 | 14 | 1 | 11 | 25.0 | 295 | 11.6 | 140 | 8.5 | 200 | 4 | 171 | -DO- |
| 7-1-72 @ 1050 | 28 - 42 | 8 - 13 | 23 - 25 | 23.5 | 305 | 7.2 | 84 | 8.2 | 204 | 0 | 167 | -DO- |
| 7-2-72 @ 1040 | 76 - 80 | 20 - 17 | 53 - 50 | 22.5 | 305 | 8.0 | 91 | 8.2 | 204 | 0 | 167 | |
| 7-3-72 @ 1640 | 40 | 8 | 45 | 23.5 | 300 | 8.9 | 104 | 8.3 | 208 | 0 | 171 | |
| 7-4-72 @ 1010 | 720 | 300 | 1000 | 21.0 | 300 | 8.9 | 99 | 8.3 | 204 | 0 | 167 | Runoff yesterday. |
| Current River above Big Spring Site 14 | | | | | | | | | | | | |
| 6-30-72 @ 1710 | 36 | 12 | 150 | 25.0 | 300 | 12.8 | 154 | 8.5 | 200 | 4 | 171 | |
| 7-1-72 @ 0820 | 160 | 10 | 62 | 23.0 | 300 | 7.2 | 83 | 8.2 | 204 | 0 | 167 | |
| 7-2-72 @ 0830 | 260 | 12 | 85 | 22.5 | 300 | 7.2 | 82 | 8.2 | 208 | 0 | 171 | |
| 7-3-72 @ 1600 | 70 | 5 | 43 | 24.0 | 305 | 9.2 | 108 | 8.3 | 208 | 0 | 171 | |
| 7-4-72 @ 0915 | 2400 | 620 | 2100 | 21.5 | 290 | 8.5 | 95 | 8.0 | 200 | 0 | 164 | Runoff yesterday. |
| Big Spring near Van Buren (at mouth) Site 15 A | | | | | | | | | | | | |
| 6-30-72 @ 1730 | 60 | 5 | 21 | 14.5 | 310 | 8.4 | 82 | 7.7 | 208 | 0 | 171 | |
| 7-3-72 @ 1520 | 50 | 4 | 25 | 14.5 | 320 | 5.6 | 54 | 7.6 | 208 | 0 | 171 | |
| 7-4-72 @ 0830 | 110 | 7 | 26 | 14.0 | 305 | -- | -- | 7.5 | 204 | 0 | 167 | |
| Big Spring near Van Buren (150 ft below mouth) Site 15 B | | | | | | | | | | | | |
| 6-30-72 @ 1730 | 42 | 10 | 18 | 14.5 | 300 | -- | -- | 7.7 | 208 | 0 | 171 | |
| 7-1-72 @ 0840 | 64 | 6 | 18 | 14.0 | 310 | 8.4 | 81 | 7.5 | 208 | 0 | 171 | |
| 7-2-72 @ 0905 | 60 | 5 | 20 | 14.5 | 295 | 6.4 | 62 | 7.9 | 216 | 0 | 177 | |
| 7-3-72 @ 1525 | 54 | 3 | 24 | 14.5 | 320 | 5.6 | 54 | 7.6 | 208 | 0 | 171 | |
| 7-4-72 @ 0835 | 130 | 9 | 26 | 14.0 | 305 | 8.4 | 81 | 7.5 | 204 | 0 | 167 | |
| Big Spring near Van Buren (1,000 ft below mouth) Site 15 | | | | | | | | | | | | |
| 7-1-72 @ 0850 | 44 | 12 | 21 | 14.5 | 295 | 8.4 | 82 | 7.6 | 204 | 0 | 167 | |
| 7-2-72 @ 0915 | 46 | 7 | 32 | 14.5 | 300 | 6.6 | 64 | 8.0 | 212 | 0 | 174 | |
| 7-4-72 @ 0850 | 88 | 8 | 24 | 14.0 | 305 | 8.4 | 81 | 7.5 | 204 | 0 | 167 | |

consistently low numbers of bacterial colonies; total coliform counts were between 10 and 70, fecal coliform 0 to 25, and fecal streptococci 10 to 70 with one abnormal value of 150. A large increase in visitors throughout the Riverway occurred Friday night, with additional arrivals Saturday. The weather was warm Saturday, which led to considerable use of the rivers for swimming, especially near Alley Spring. This caused a general doubling to tripling in bacterial counts except at Big Spring where the water being sampled had travelled underground for several days. The very high values at site 6, above Swampy Campground, are most probably the result of a large number of equestrian "trail-ride" horses crossing and recrossing the river at several shoals within 1 mile above the sampling station. These large groups of horses were observed to add considerable equine fecal material directly to the river. The consequences of this use of the river for trail rides should be considered in planning for future development of the area. The most heavily used swimming area in the Riverway, at the time of the study, was immediately downstream from these trail-ride crossings between sites 6 and 7.

By Sunday, July 2nd, the weather had turned cool and heavily overcast, with some rain showers Sunday afternoon. The visitor attendance and corresponding use of the river declined Sunday afternoon and evening. The samples collected Monday generally showed a corresponding decrease in bacterial counts. Rain became widespread and more intense on Monday, and generally produced light to moderate surface runoff Monday evening. The counts from samples collected Tuesday were five to fifty times higher than the "background" counts found on Friday and Saturday, June 30 and July 1, and were much more variable. At sites 3, Round Spring, and 6, Swampy Campground, the runoff-related increases in total coliform and fecal

streptococci on Tuesday, the 4th, were generally larger than the increases in fecal coliform, causing an increase in the ratios of total coliform and fecal streptococci to fecal coliform. The opposite was noted at site 14, above Big Spring, where high ratios prevailed initially.

Several departures from the above generalities are notable in the data (Table 3). At site 3, Round Spring, the Saturday, July 1, fecal coliform count of 5 is numerically quite small. If this had been 5 to 10 counts higher, which is well within the range of sample variability, the ratios of fecal coliform to total coliform, and fecal strep. to fecal coliform, would have been essentially constant for Friday, Saturday and Sunday.

At site 6, Camp Swampy, the July 1 count of fecal strep, 96, is abnormally low compared to the fecal and total coliform counts on the same day. Because only one sample was collected each day at this site, it is impossible to determine whether this abnormal value was the result of some interference in the testing or was a valid test of unusual conditions. The July 3 fecal coliform count at this site is so small that the remarks about the site 3 July sample, above, pertains here also.

The samples from Big Spring Branch show conflicting results. Total coliform counts from same-day samples generally show a downstream decrease. For examples, the June 30 total coliform counts decrease from 60 to 42, the July 1 values decrease from 64 to 44. July 4 was the only date on which all three sites were sampled; the results in downstream order are 110, 130, and 88. The same-day counts of fecal coliform and fecal streptococci increase downstream as often as they decrease downstream. This may simply indicate sampling (or analysis) variability in measuring essentially constant values of 7 fecal coliform and 23 fecal streptococcal colonies per 100 milliliters.

Table 4 lists the results of the July 1, 2, and 3 samples collected and analyzed by the USGS team and the July 2 samples collected at the same sites and tested by UMR personnel. Results from half the sites (numbers 9, 12 and 15) are in close agreement. Differences up to more than an order of magnitude were obtained from sites 3 and 6. The largest difference was observed in total coliform count from site 6. It is likely, considering the ratios between fecal and total coliform, and fecal strep and fecal coliform, that the UMR count of 8 is not representative. Perhaps it should be in 70-90 range. In all instances where there is a large difference, the UMR value is less than the USGS count. The comparison shows that variability up to an order of magnitude frequently occurs in these rivers.

Table 4

Comparison of USGS and UMR Results

| | | Type of Test | USGS 7-1 | USGS 7-2 | UMR 7-2 | USGS 7-3 |
|---|---|---|---|---|---|---|
| 3. | Current River, Below Round Spring at Group Campground | Total Coli | 36 | 280 | 121 | 110 |
| | | Fecal Coli | 5 | 140 | 6 | 17 |
| | | Fecal Strep | 43 | 320 | 380 | 93 |
| 6. | Jacks Fork, Above Swampy Campground | Total Coli | 960 | 350 | 8 | 140 |
| | | Fecal Coli | 490 | 42 | 4 | 6 |
| | | Fecal Strep | 96 | 160 | 47 | 140 |
| 7. | Jacks Fork, $\frac{1}{4}$ mile above Alley Spring Branch | Total Coli | | | 49 | 210 |
| | | Fecal Coli | | | 5 | 44 |
| | | Fecal Strep | | | 33 | 280 |
| 9. | Jacks Fork, Below Eminence Center Channel | Total Coli | 160 | 100 | 120 | 180 |
| | | Fecal Coli | 27 | 82 | 30 | 30 |
| | | Fecal Strep | 78 | 160 | 120 | 96 |
| 10. | Jacks Fork, Below Eminence Right Side | Total Coli | 84 | 400 | 86 | 320 |
| | | Fecal Coli | 40 | 200 | 53 | 48 |
| | | Fecal Strep | 280 | 240 | 160 | 170 |
| 12. | Current River, At Deer Run Campground | Total Coli | 16 | 92 | 80 | 86 |
| | | Fecal Coli | 1 | 3 | 4 | 30 |
| | | Fecal Strep | 15 | 19 | 30 | 140 |
| 15. | Big Spring Branch, At Spring Mouth | Total Coli | 64 | 60 | 88 | 50 |
| | | Fecal Coli | 6 | 5 | 3 | 4 |
| | | Fecal Strep | 18 | 20 | 18 | 24 |

Water Quality Methods and Procedures

The methods used for both the three-month study and the short-term study followed those described in Part 400 of "Standard Methods for the Examination of Water and Wastewater, Thirteenth Edition" (Taras et al, 1971). The membrane filter procedure described in Part 408 of the "Standard Methods" was followed for all bacteriological testing.

For the three-month study, water samples were collected in one-pint glass bottles which had been capped, aluminum foil covered, and autoclaved. Usually, two to four bottles were filled in rapid succession at each sampling site. Immediately after filling with approximately 400 milliliters of river water, the tightly capped sample bottles with foil covers were partially immersed in an ice-water bath in an insulated chest, for transportation to the UMR campus laboratory. Transportation times ranged from three to six hours depending upon remoteness of the sites.

For the short-term study, samples were collected in one-liter polyethylene bottles. The sample bottles were rinsed with sterile water before being filled with river water. Because all of the short-term samples were immediately filtered in a motorized field laboratory driven to within a few hundred feet of each sampling site, transportation times were negligible. At each site the membrane filters with nutrient pads in culture dishes were placed in incubators before moving the lab to the next site.

In addition to the difference in transportation of samples, there was a difference in the methods of incubation used by the USGS team and the UMR personnel. The "Standard Methods," 13th edition, emphasizes that fecal coliform test filters must be incubated at a temperature of $44.5^{\circ}C \pm 0.2^{\circ}C$. In the UMR Life Sciences laboratories several large water bath regulators were carefully tested with sensitive thermometers. It was found that some

of the commercially available laboratory water heaters and regulators could not hold the temperature within the plus or minus 0.2°C required over a twenty-four hour period. Only by using a research quality regulator, a large volume bath (2 gallons or more), constant stirring, and an insulated cover, was it possible to maintain the close tolerance required. In the USGS mobile field laboratory, a Millipore brand portable water bath incubator was used. This incubator has the advantage of being powered by a 12 volt supply in the mobile van and a 115 volt adapter overnight. It "was designed specifically for use in the Standard Fecal Coliform Test" (Millipore, 1972). Although the equipment was designed to hold the required tolerance, in normal field use the limits were frequently exceeded. In use, a metal rack which holds plastic bags of petri dishes fills the small volume of the water bath. As the rack is filled, nearly half of the water volume of the incubator chamber is displaced. Each time new samples are added, the rack must be partially removed from the incubator, at which time evaporation from the rack and samples causes a rapid temperature drop. For several minutes during and after the addition or removal of samples, the temperature of the bath may be more than a degree below 44.5°C. The effect of these short-term interruptions is unknown. The U.S. Geological Survey Water Resources Division has had extensive experience with their procedure and have not observed any adverse effect.

A further difficulty arose in the identification of colonies cultured on the membrane filter. The membrane filter procedure basically consists of forcing a water sample through a flat filter disc which traps and holds the individual sub-visible bacteria, then incubating the filter disc in contact with a nutrient for a limited period, usually twenty-four hours. During incubation the individual bacteria each form colonies large enough

to be seen by the unaided eye, or seen easily with low magnification (2x-10x). The nutrients used during incubation are highly selective, causing growth of the bacteria sought and suppressing other growth. All of the waters collected in this study included additional non-coliform organisms which reproduced and formed visible colonies on the filter discs along with the coliform colonies. A dye used in the nutrient is supposed to cause a golden green metallic sheen to form on the surface of the coliform colonies, and only those colonies having the green metallic sheen are to be counted as coliform. Even under laboratory conditions, using fluorescent lighting of optimum wavelength, there is often difference of opinion among trained experienced observors about the presence or absence of the sheen. In routine testing, many colonies (up to 200) must be identified and counted on each filter disc and sometimes more than twenty discs are counted per hour. There is usually little opportunity to contemplate and confer with colleagues about the presence of the sheen on each colony. This leads to variability in the counting of total coliform colonies. In the UMR study much effort was spent trying to develop consistency in the identification of the coliform colonies. Many filter discs were counted each by three or more observers. Some discs were recounted at different times by each of three observers. And some filter discs were examined colony-by-colony in conference to obtain agreement of opinion. Similar standardization procedures had been followed by the USGS personnel in their training in previous years. However, during the intensive "4th of July" study, differences of opinion amounting to 5 to 20 percent of the total coliform count per filter disc occurred among five observers (2 from USGS and 3 from UMR) upon multiple examinations of several discs.

The difficulty of identifying coliform colonies is limited to the total coliform test. The nutrients, dyes, and incubation procedures used for the fecal coliform and fecal strep tests lead to growths which can be identified visually with much greater certainty. In conversation with water quality workers from several parts of the country, and from the literature, this author (Maxwell) has noticed a bias in favor of the latter two tests and against the total coliform test. This bias seems to be based at least in part on the difficulty of identifying the green metallic sheen in the total coliform procedure. As an example, the Missouri Clean Water Commission, in complying with the Federal Water Pollution Control Act, has set standards of fecal coliform, but not total coliform, for Missouri interstate rivers. Yet of these three most widely used tests (total coliform, fecal coliform, and fecal streptococci), the total coliform was first developed and has been most widely tested. The currently popular fecal streptococcal test is still a tentative procedure. The effect of imperfect temperature control during incubation in the fecal coliform procedure may be considerable and is usually not known. The significance and meaning of both fecal coliform and fecal streptococci as indicators of human pollution has not been thoroughly investigated and confirmed. Thus it would seem prudent to proceed cautiously in relying exclusively on results of the latter two tests until their relationships to total coliform counts, natural (wild) environments, and human sources, have been better investigated.

# Section VII

## SUMMARY AND RECOMMENDATIONS

### Summary

The information compiled in this report indicates that the Current River Basin will become an increasingly popular tourist attraction. Its ample supply of clear, clean water, free flowing rivers and great springs and its forested hills and scenic valleys will attract more and more people seeking the refreshment of an unspoiled environment. From a total of 5 million visits to the area in 1970, the Missouri Highway Department estimates that the total number of visits to the Ozark National Scenic Riverways in 1990 will exceed 17 million. This growth with its consequent strain on water, land, economic, and human resources gives impetus to the demographic, hydrogeologic, and bacteriologic data of this report.

The demographic study (Section II) shows that much of the appeal of the Basin results from its rustic, sparsely populated, undeveloped condition. It is this very condition, of rural villages with limited services, which reveals that the area is not well prepared to cope with a three-fold increase in visitors in less than twenty years. Although expansion of the Federal and State highway network to the area is already well underway with further improvements planned, private development of public accomodation and services has been proceeding slowly. The larger towns in and adjacent to the Basin have services and facilities to provide for their present population, but may lack the governmental structures, resources, or jurisdiction to cope with rapid growth. The smaller communities generally have no plans or capability for expansion. It is

apparent that, for at least the next four or five years, the increase in number of visitors will have to be accomodated in campgrounds, by choice and necessity.

Study of published sources of hydrological data revealed that the U.S. Geological Survey has published a substantial amount of information about stream flow in the Current River Basin. This information is published in more than fifty separate papers and reports. Section III of this study includes comprehensive indexes to these data. Also included are indexes to the fewer measurements of springs in the Basin.

As part of a state-wide study, the Missouri Geological Survey measured the physical and chemical quality of water at six river sites and eight springs in the Basin in 1925 and in 1952. Regular measurements on a continuing semi-annual basis were started by the U.S. Geological Survey in 1969. Since 1971, bacteriological sampling has been included in these measurements. Indexes to the year of measurement, paper number, and page number for these data have been compiled in the report to facilitate their use.

To determine the general relationship between rainfall and stream discharge, the Current River Basin was divided into six subbasins. Monthly rainfall for each subbasin was calculated by the Theissen method for the period from 1961 to 1970. Analysis of individual monthly relationships revealed some general similarities among those months during which base flow discharge prevailed, and different relationships when discharge exceeded base flow. Monthly equations expressing these relationships predicted discharge with ninety percent accuracy. Six generalized relationships were derived by graphically combining the individual monthly curves. The results indicated areas of probable subsurface water

loss and provide a means for estimating stream discharge from a range of monthly rainfall amounts.

Two major tracer studies by Maxwell and Aley (Section V) confirmed and delineated the sources of Blue Spring and Big Spring. Tracing from Logan Creek showed that flood waters from upper Logan Creek, where new lead mines are being developed, travel very rapidly underground to Blue Spring. One trace from the outfall of the Mountain View sewage lagoon, and another exceptionally long one from the area north of West Plains, both to Big Spring, emphasize the hazards to the springs from growing population centers. Continued awareness and monitoring is needed to insure that the springs do not become polluted.

The bacteriological quality of the Riverway's water was investigated through two closely related studies. A three-month summer-long sampling at ten-day intervals provided a reconnaissance of the general levels of total coliform, fecal coliform and fecal streptococcal bacteria that can be expected. A more limited daily sampling during the Independence Day weekend showed some increase in bacteria count caused by the large increase in number of visitors, but also revealed in considerable detail the much larger increase caused by rain-induced surface runoff.

The major conclusion of our bacteriological studies (Section VI) is that the Current River and Jacks Fork have generally very low bacterial content at present. However, no criteria are available for conditions following rainfall when surface runoff occurs and bacterial counts rise rapidly. Clearly, recreational visitors will use the rivers and springs immediately after and even during summer rainstorms. The significance of high counts under such conditions needs to be determined. Increases of ten to fifty times the "normal" were observed in this study under such

conditions. Trail ride groups of horses crossing the rivers had an adverse effect on bacteriological quality. No evidence was found of pollution from any of the sewage lagoons adjacent to the rivers.

## Recommendations

Based on the work done for this report there is one clearly needed general recommendation: Monitoring of the conditions that affect the quantity and quality of the water resources of the Current River Basin should be continued on a regular basis. This monitoring should be continued on a regular basis for all factors until each factor is stabilized and controlled. Then the monitoring for the controlled factors could be changed to an irregular basis depending upon the relative cost of monitoring and reliability of control. Detailed recommendations of objectives and sites for additional investigations are presented below in the same sequence as the topics in the body of the report above.

### Demography

Additional monitoring of the demographic changes in the Basin is needed. Although very good programs are apparently in effect to monitor the number of floaters and campground users in the Riverways, little seems to be in progress to monitor Basin-wide population densities and community services, both of which could have great impact on water resources. Files of such information were established for this study; they could be updated and improved for relatively modest cost. We recommend that data on communities of one thousand or more population be revised at least every six months, in order to be aware of any plans for modification of storm and sanitary sewage, waste disposal, and residential or industrial develop-

ment while still in the planning stage. If handled properly such a monitoring program could be a vehicle for improving public relations and increasing the resident public understanding and awareness of the possible hazards of groundwater contamination in karst terrain.

Close coordination should be established and maintained with the Ozark Foothills and South Central Regional Planning Commissions, and with local mayors and Chambers of Commerce. Some of the monitoring recommended above is already being done, on an if-as-and-when-possible basis, by the Regional Planning Commissions. An obvious opportunity exists here for the Riverways to establish cooperative programs.

Files on facilities should include one specifically on motels because some motels may be outside the areas covered by the communities file. It is pertinent to the water quality of the Riverways to know about the sewerage disposal and approximate capacity and occupancy of all the motels in the Basin.

## Hydrologic Data

The U.S. Geological Survey, cooperatively with the Missouri Geological Survey, already has an excellent ongoing program of surface flow measurements. The only recommendation on this is that they be encouraged to continue this program. Their present program of water quality measurements is improving but still rather minimal. It is recommended that water quality measurements be increased to four times per year, from the present two, at the larger springs, and that water quality measurements be initiated on a quarterly basis at the Current River near Eminence station and, if possible, at Jacks Fork at Eminence. In recognition that cost is almost directly proportional to the number of measurements, it is recom-

mended that, if necessary to provide for the increases above, measurements be reduced to once per year at Welch and Pulltite Springs, and perhaps at Round Spring.

The compilations of sources of published data, in Section III, above, were intended to provide easier access to these data. Several minor discrepancies were noted between the published measurements of springs and several published lists (Vineyard and Feder, 1974) of dates when spring measurements were made. After the lists in this report have been available to Riverways personnel and other investigators, comments on their format should be solicited. The lists should then be revised as necessary to resolve the minor discrepancies, update the data, and improve the format for maximum utility.

## Rainfall-Runoff Relationships

A substantial defect was found during study of the rainfall data for the Basin. As noted in Section IV, large differences were found between data from non-recording gages and those from recording gages. This limits the usefulness of both sets of data. The study described in this report shows some possibly useful relationships but also shows that some of the factors affecting runoff have not yet been adequately identified or measured. It is recommended that both of these problems be investigated further, using a variety of mathematical methods and new data as they become available. Because there is less urgency to these investigations than to those concerning water quality, they could perhaps be pursued as sponsored academic research.

## Tracer Studies of Spring Sources

Although the presently most critical sources of the area's two largest springs (Logan Creek to Blue Spring and Mountain View's lagoon to Big Spring) have been identified, much work remains to more clearly define the subsurface drainage divides in the Current River Basin. Usually the intermediate to smaller sized spring subsurface drainage areas are more difficult to identify because smaller, slower flows of water are involved. In areas such as the uplands near Montauk Springs and the dry valleys near Summersville, tracing can be accomplished only during an "ideal size" rainstorm. Too small a storm will not carry the dye into or through the underground channel system; too large a storm will cause normally dry surface streams to flood, carrying the dye to outlets other than those normally used. Specific sites are described in Section V above. Montauk, Welch, Round, and Alley Springs, in that order, are recommended for most urgent consideration. The priority is based on the proximity to growing population centers and sources of possible pollution, as well as significance of the flow of the springs to the Riverways.

It is recommended that future spring tracing studies be done on a cooperative basis utilizing both outside investigators and Riverways personnel. Because some Riverways personnel presently travel throughout the area on their normal duties, and have a well established communication network which is essential to tracer studies, a few of these persons could be trained to assist with the relatively simple but exacting field work. Because tracer studies must be done on a "when-possible" basis, it is recommended that a moderately long-range, five to eight year program be planned. After the initial training, a priority sequence of alternative plans could be executed according to weather and river conditions.

## Bacteriological Water Studies

The reconnaissance studies done for this report provided a good indication of the present bacteriological quality of the Basin's waters. Equally important, they gave some indication of the week-to-week variability to be expected. Thus far there is little data available anywhere, and none from the Current River, to indicate how representative a single sample might be, or what the diurnal variability may be. It is recommended that the U.S. Geological Survey program of measuring bacteriological concentrations at infrequent intervals be continued for monitoring purposes and that one or more special investigations be undertaken to determine short-term bacterial variability and the precision and accuracy of the measurement procedures. It is recommended that bacteriological analyses be made of samples collected from a single site at six hour intervals for a period of four days, including a weekend. During the four days of six-hour sampling intervals there should be at least two three-hour periods of sampling at half-hour intervals. And on several occasions during the test three or more samples should be taken simultaneously and treated as separate samples. This investigation would require some careful advance planning to provide adequate supplies, space and equipment for the volume of samples to be processed, and to avoid confusion among samples with overlapping filtering and incubation times.

The results of this above first test of variability should be used to design at least one more test at the same site during a different season of the year. The first test may indicate, for example, that a 7:00 AM, 9:00 AM, 12 noon, 2:00 PM, 4:00 PM, 8:00 PM, and midnight sampling sequence might provide much more information about effects of swimming and other recreational activities. Or it may show that only two properly

timed samples each day are sufficient to measure the entire range of variability.

After the second test at the same site, at least one more investigation should be made at a different site. The results of these three tests should indicate whether similar tests are needed at other times of the year or at other river or spring sites. It is recommended that at least one of the tests be done on Jacks Fork below the bathing and camping area but above the confluence of Alley Spring Branch, in order to monitor the effect of recreational activities. One of the other tests should be done below Van Buren but above Big Spring, to measure the effect, if any, of the town as well as those of the several campgrounds near Van Buren.

The second major bacteriological recommendation mentioned above, of testing the measurement procedure, could be done either independently of or in conjunction with the four-day tests. Equal portions of single large samples should be analyzed by the U.S. Geological Survey personnel and by at least one other research facility. This test should be repeated until the results agree closely several times or until reasons for the differences have been well identified.

Separate from the above recommendations is the need for better criteria and knowledge of bacterial hazards during periods of storm runoff. It is apparent that visitors to the Riverways will use the rivers during and soon after summer showers and heavy rainstorms. Few data are available on the bacterial populations to be found in free-flowing rivers under such conditions, or whether the usually tested coliform and streptococci are valid indicators of other pathogenic bacteria and viruses under these conditions. Although such research might better be done at specialized centers such as the Taft Center in Ohio, an initial impetus from field

studies would provide significant motivation. So we recommend that, when possible, bacteriological analyses be made of samples collected during periods of moderate and intense surface runoff.

A final recommendation concerns the tests used. The presence of coliform bacteria in water indicates the presence of impurities in the water. The relationship of fecal coliform to total coliform in general, and in the Current River Basin specifically, is very poorly defined. Therefore it is strongly recommended that both be measured, until the nature of the impurities which each indicates in the Current River is well established.