THE UNIVERSITY OF MISSOURI BULLETIN

VOLUME 21, NUMBER 35

ENGINEERING EXPERIMENT STATION
SERIES 22

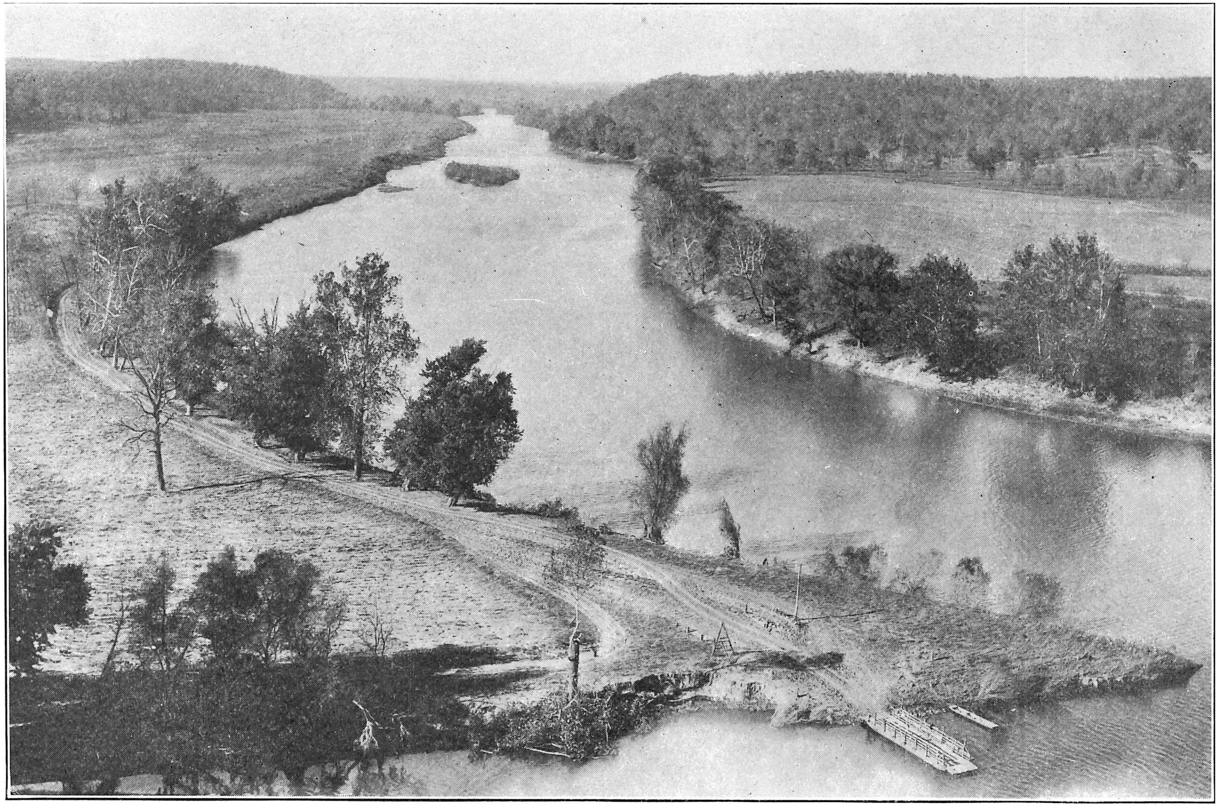
Study Relating to the Water Resources of Missouri

BY

T. J. RODHOUSE
Professor of Hydraulic Engineering

ISSUED THREE TIMES MONTHLY; ENTERED AS SECOND-CLASS MATTER AT THE POSTOFFICE AT COLUMBIA, MISSOURI—3,000

DECEMBER, 1920



Where the Niangua and Osage Rivers Meet. Typical Topography of the Ozark Streams.
[Photo by J. K. Wright]

THE UNIVERSITY OF MISSOURI BULLETIN

VOLUME 21, NUMBER 35

ENGINEERING EXPERIMENT STATION
SERIES 22

Study Relating to the Water Resources of Missouri

BY

J. T. RODHOUSE
Professor of Hydraulic Engineering

ISSUED THREE TIMES MONTHLY; ENTERED AS SECOND-CLASS MATTER AT THE POSTOFFICE AT COLUMBIA, MISSOURI—3,000
DECEMBER, 1920

CONTENTS

CONTENTS—(Continued)

ILLUSTRATIONS.

STUDY RELATING TO THE WATER RESOURCES OF MISSOURI

INTRODUCTION

Importance of stream discharge.—In any proposition relative to river improvements, whether it has to do with drainage, flood protection, water power, navigation, water supply, or sanitation, a factor of prime importance is the actual discharge of the stream. In order that any proposed improvements may be carried on to best advantage it is imperative that the discharge of the stream, including both seasonal and daily flow, be known within reasonable limits of accuracy.

Stream measurements.—To obtain information relating to the discharge of any water course that is most useful and reliable, the observations should extend over several years. The maximum, average, and minimum flow of a river, and the duration of these various stages during the seasons of the year, or thru a series of years, are frequently the controlling factors in proposed improvements. Reliable data on the flow of a stream can be obtained only by a series of observations extended over sufficient time to eliminate the misleading effect of unusual seasonal conditions. The value of the data will depend largely on the care exercised in the methods of making the measurements and upon the length of time over which the observations are extended.

State policy respecting use and control.—There is no question confronting the people of the state of greater economic importance than that of the proper regulation and use of their water resources. The state should mark out its policy with respect to its streams and watercourses which shall establish the principles and procedure governing their use and control, whether these resources pertain to water power, water supply for municipal purposes, benefits to navigation, drainage and leveeing for agricultural purposes, or for the benefits and protection of public health.

A serious mistake which a state can make is to fail to realize the value and permanency of its water resources, and to permit the granting of special water rights or privileges, which may, instead of becoming of the greatest benefit to the people in general, become in many cases practically useless for a long period. On the other hand the state should not adopt any policy that will in any way become a hindrance to the development of its water resources providing such development is for the benefit of the best interests of the people of the commonwealth.

Conservation based on knowledge.—Progress in the development of a state's resources ought not to be delayed either by neglect on the part of the state to encourage their utilization or by adopting a policy which places too many restrictions upon their use. The only way to conserve the water resources is to use them, and to use them properly is a privilege which should be granted by the state only to such persons as are bound to regard the rights and interests of the people of the state. To institute such a policy as shall make possible the best use of the water resources it becomes necessary for the state to know more concerning its streams and water courses than is now known. This matter of information regarding stream flow is of prime interest to the state as a whole, as well as to its individual citizens.

Permanency of water resources.—A striking feature regarding water resources which appeals to all is their permanency. They are never dissipated nor are they exhausted in the least by use. They are continuously renewed with each recurring season. They may be neglected and be permitted to run to waste, or they may be utilized as time goes on for the benefit and welfare of the people. They are a permanent possession and cannot be destroyed.

Economic value of water power.—As an illustration, the most economic value of water power does not necessarily lie in the fact that it is a cheaper source of energy than fuel. Its greatest economic value may arise from the fact that its development and use conserves the energy in fuel, which would be entirely consumed in the development of an equal amount of power. When the fuel is once used it is completely dissipated and can never be recovered, while in the case of the water it is permanently recurrent and always available for supplying the same amount of energy tomorrow as it supplies today.

Value of full information.—The time is rapidly approaching when it will be of utmost advantage to the state to be in possession of complete information regarding all of the water resources within its borders. The large number of small towns widely distributed thruout the state are already confronting serious problems of water supply and of stream contamination. The interests of public health demand that these problems be solved intelligently and effectively under state advice and control. Drainage and reclamation of lowlands is the development of a natural resource requiring more complete information on the discharge of surface water from hill land and valleys. Excessive discharge of water at flood periods from improved drainage districts above on unprotected districts farther down stream complicates the problem. An intelligent and satisfactory solution of such problems will require that the state have at its command the fullest reliable information regarding the conditions of stream flow in such localities.

Regulating stream flow.—The effect of artificial storage on steadying stream flow, and the discharge of streams as affected by deforesting large areas of timber land are matters of importance which should receive serious consideration. The construction of reservoir systems on the upper reaches of many of the streams of the state certainly is practically possible, and it is clearly evident that such systems of storage would greatly increase the low water flow and materially lower the damaging flood conditions. To increase the low water flow would improve very considerably the conditions for power development, and to reduce the flood stages of a river would to a great degree obviate much of the disaster to farming interests from high waters. Both of these effects are greatly to be desired. The effect of forests on improving the regularity of stream flow is not yet definitely determined. There is much evidence indicating material beneficial effects from forest covering over the watersheds of many streams. It is desirable that the facts relating to the effect of forest covering on stream flow, especially in the Ozark region, be more definitely determined, in order that this factor, if important, may be given due consideration.

Related factors involved.—It is important that extensive improvements along the various rivers and water courses be undertaken in such a comprehensive way as will have due regard for all of the closely related factors connected with the problem as a whole. Most generally such problems as protection from overflow, drainage, storage, backwater, and power development within a watershed are closely related, and the plan of improvement which includes all of these propositions in their relations to each other will in the end be the most economic and satisfactory.

Purpose of this report.—A comprehensive study of the apparent erratic action of streams reveals the fact that they are controlled by natural laws, often not clearly defined nor well understood. It is the purpose of these investigations to finally present sufficient data concerning the various phenomena relating to stream flow on Missouri streams as will establish relationships from which more trustworthy conclusions can be drawn and on which the success of various kinds of hydraulic work may safely depend. This preliminary report is contributed at this time in order that the information already collected may be available for earliest possible service.

THE YIELD OF A SMALL WATERSHED NEAR COLUMBIA, MISSOURI

Observations to determine the run-off, or yield, from smaller watersheds near Columbia, Missouri, have been carried on for several years. Unfortunately, practically all of the writer's field notes and data collected were consumed in a fire that destroyed one of the University buildings in which his office was located. The writer regrets that it is impossible to report on more than a small portion of the observations made, since the results indicated unmistakably that the yield of small watersheds in the central part of the state north of the Missouri River is considerably less during extended dry seasons than it is usually estimated to be. However, some fragments copied from the original records have been collected, and it is possible to present a continuous record of a run-off from a drainage area of 14.7 square miles from January 1, 1910, to June 30, 1911.

Grindstone Creek watershed.—This stream has its headwaters about five miles east of Columbia, in Boone County, Missouri, and extends in a general southwesterly course a distance of five miles, discharging its waters into the Hinkson Creek basin at a point about one mile southeast of Columbia. The watershed is nearly rectangular in form. It is approximately five miles long and averages about three miles wide.

Geology.—The watershed covers an area underlaid with crystalline limestone as a base. Overlying this base are fire clays, coal measures and shale varying considerably in depth. The surface covering is mainly impervious clay with a top surface of five to twenty inches of fertile soil.

Topography.—The topography is that of gently rolling prairie land in the upper half of the watershed, becoming more rugged and precipitous in the lower portion. Tilled farming land, with open pastures, comprises about two-thirds of the whole area, while most of the more rugged portion is fairly well wooded. The number of springs is very small, indicating that there is very little percolation.

This watershed is, in every respect, quite typical of those in central Missouri lying north of the Missouri River. Many of these watersheds are much used by the smaller towns and cities for furnishing municipal water supplies.

Yield.—Observations on the discharge from this watershed are presented in the table below. The measurements of discharge were made by means of a current meter for the ordinary and high-water stages of the stream, and by means of a six-foot sharp-crested weir during the low-water stages. The daily stages of the stream were observed by means of a graduated gage plank set in a vertical position.

The rainfall records are those of the local office of the U. S. Weather Bureau at Columbia, Missouri. The rain gage is outside the watershed and about one mile from its border. It was noted that local showers were occasionally recorded by the rain gage when that part of the drainage area most distant from the gaging station received only a trace of rain. It is believed, however, that the average conditions of precipitation for each month were fairly well distributed over the whole watershed.

Referring to the table it will be noted that the total rainfall for 1910 was 42.22 inches, and that the total yield from the watershed was 15.74 inches, or a ratio of run-off to rainfall of 37.3 per cent. It is further apparent from the table that the first six months of the following year produced a rainfall of only 13.05 inches with a run-off of 3.33 inches, or a ratio of run-off to rainfall of only 25.5 per cent.

YIELD OF GRINDSTONE CREEK WATERSHED NEAR COLUMBIA, MISSOURI, FROM JANUARY 1, 1910 to JUNE 30, 1911

(Drainage Area 14.7 sq. mi.)

Month	Discharge in sec. ft. per sq. mi. (Average)	Total yield in acre-feet* per sq. mi.	Rainfall in inches on drainage area	Run-off in inches on drainage area	Ratio of run-off to rainfall (per cent)
1910					
January	1.70	104.3	2.36	1.99	84.2
February	0.51	28.2	1.09	0.53	48.8
March	0.53	32.6	.64	0.61	94.7
April	0.62	37.8	3.82	0.68	17.9
May	3.46	212.3	6.82	3.97	58.3
June	2.88	171.0	5.67	3.19	56.4
July	1.75	107.6	5.25	2.01	38.2
August	0.80	49.2	4.40	0.91	20.7
September	1.44	88.5	10.36	1.68	16.2
October	0.07	4.3	0.67	0.08	11.9
November	0.07	4.2	0.33	0.07	23.5
December	0.01	0.6	0.81	0.02	1.9
The year	1.17	840.6	42.22	15.74	37.3
1911					
January	0.09	5.5	0.96	0.10	10.8
February	0.90	49.9	3.04	0.94	30.7
March	0.45	28.0	1.54	0.52	33.8
April	1.46	86.7	5.65	1.60	28.4
May	0.12	7.4	1.27	0.14	11.1
June	.03	1.8	0.59	0.03	5.6
The half year	....	179.3	13.05	3.33	25.5

*An acre-foot means one acre in area one foot deep, and is equal to 43,560 cubic feet.

The later summer, fall and early winter months, generally having small amounts of rainfall, in this region, have greatly reduced percentages of run-off. It is very evident that an extended period of several months of continuous drouth is most likely to produce a condition of exceedingly low percentage of run-off and a consequent low yield from the watershed. Such a condition producing a shortage in the yield from this watershed is frequently realized over periods of from six to nine months, and occasionally over periods from twelve to sixteen months.

As an example of a condition producing an extremely low discharge or yield from this watershed the period from November 1, 1900, to February 28, 1902, may be cited. This period of sixteen consecutive months received a total rainfall in this drainage area of only 24.91 inches, or practically half the normal rainfall for this length of time. With the percentage of run-off greatly reduced, as is indicated in the table for months of low rainfall, it is very evident that probably not over six inches depth of run-off would be realized from this watershed in a period of a year to sixteen months under such extreme dry weather conditions.

Effects of extremely low yields.—Special attention is directed to such results for the reason that many of our smaller towns and cities in central Missouri have met with considerable distress on account of a shortage in their municipal water supplies during the past few years. This shortage was undoubtedly due to a failure to realize the fact of a possible very low yield from small watersheds in this region over extended periods of drouth, and thus failure to provide sufficient storage to tide over such extreme conditions resulted.

A probable annual yield of only six to eight inches of run-off may not be too low as an estimate for occasional years of very low rainfall. It is hoped to extend these investigations over a much longer period of time, and on several typical smaller areas of varying extent.

SPRINGS OF THE CENTRAL OZARK REGION IN MISSOURI

A number of very large springs are well distributed over a large part of the Ozark region* in south-central Missouri. These springs are noted for the large quantity and excellent quality of the water which they deliver, and for the very remarkable scenic beauty of their surroundings.

During extended dry-weather periods the influence of these

*The origin and geology of these springs is reported in Water Supply Papers, Nos. 110 and 145, U. S. Geological Survey.

springs on the discharge of many of the rivers of the Ozarks is very marked. The minimum flow of these rivers is greatly increased by the springs, and is much greater than the flow of the streams of equal drainage areas in North Missouri, where no no such springs are to be found. Careful measurements of the discharge of a number of these noted springs were made while conducting preliminary examinations on some of the rivers for the purpose of locating gaging stations. These measurements were made by means of a current meter under very favorable conditions. The results are believed to be accurate and reliable.

SPRINGS OF THE NIANGUA VALLEY

Bennett's Springs.—Three large springs were observed on the Niangua River. The largest of these is Bennett's Spring, on the east side of Dallas County, near the Laclede County line. The spring issues from a large circular basin about thirty feet in diameter in a gravel bed lying in the narrow valley of a small creek. It flows from this source one and a half miles to empty into the Niangua. The fall from the head of the spring to the level of its outlet at the river is 22.7 feet. The spring at present furnishes ample power under a six-foot head for a small mill at the village of Brice nearby.

Figure 1, page 15, is from a photograph of this spring.

A gage was established on this spring September 3, 1916, and daily records of its flow have been kept up to the present time. Measurements of the discharge were made at various times with the Price current meter and the rating curve established which, with the gage readings, indicates the variation in the flow of the spring during different seasons of the year.

The variation in the flow of Bennett's Spring for the four years' observation is indicated by the discharge curve shown on page 16. The minimum flow during the period was 75 cubic feet per second, and the maximum was 163 cubic feet per second. The average flow was 110 cubic feet per second, or 71,300,000 gallons per day.

The relation between the flow of Bennett's Spring and rainfall on the area in the vicinity of the spring is shown on the same chart. It will be observed that the variation in the flow of the spring seems to lag behind the rainfall periods by about thirty days. The rainfall records* for Lebanon, Mo., were used. The distance from the spring to Lebanon is about 12 miles.

Apparently about 75 per cent of the flow of this spring is deep ground water coming from a distance considerably farther away than

*U. S. Weather Bureau records.

PLATE II.

Fig. 1. Bennett's Spring, on the Niangua River

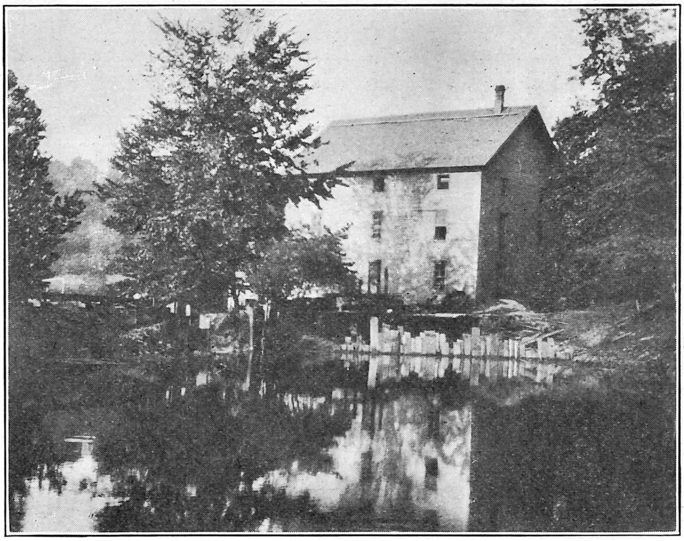
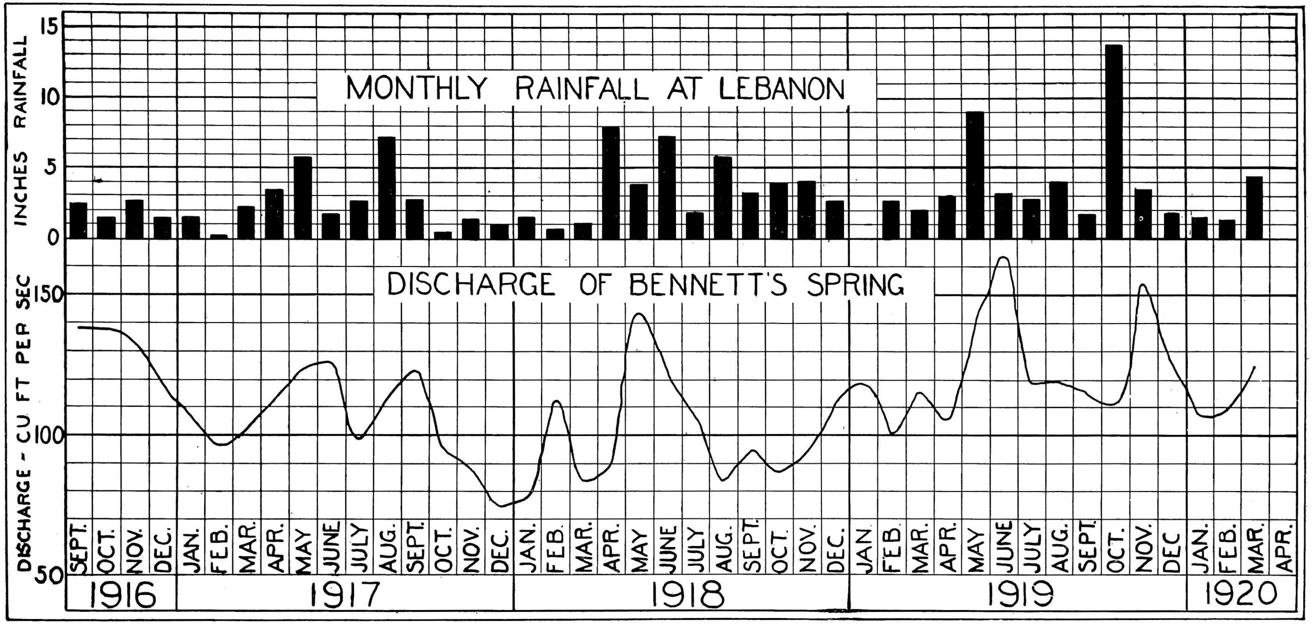


Fig. 2. Alley Spring, on Jack's Fork of Current River

PLATE III.



Discharge Curve of Bennett's Spring

Lebanon. The underground water storage is therefore very great and results in the remarkably steady flow of this spring. There is every indication that the flow of Bennett's Spring with its relatively small variation from the mean or average is quite typical of the flow of the other large springs of the Ozark region.

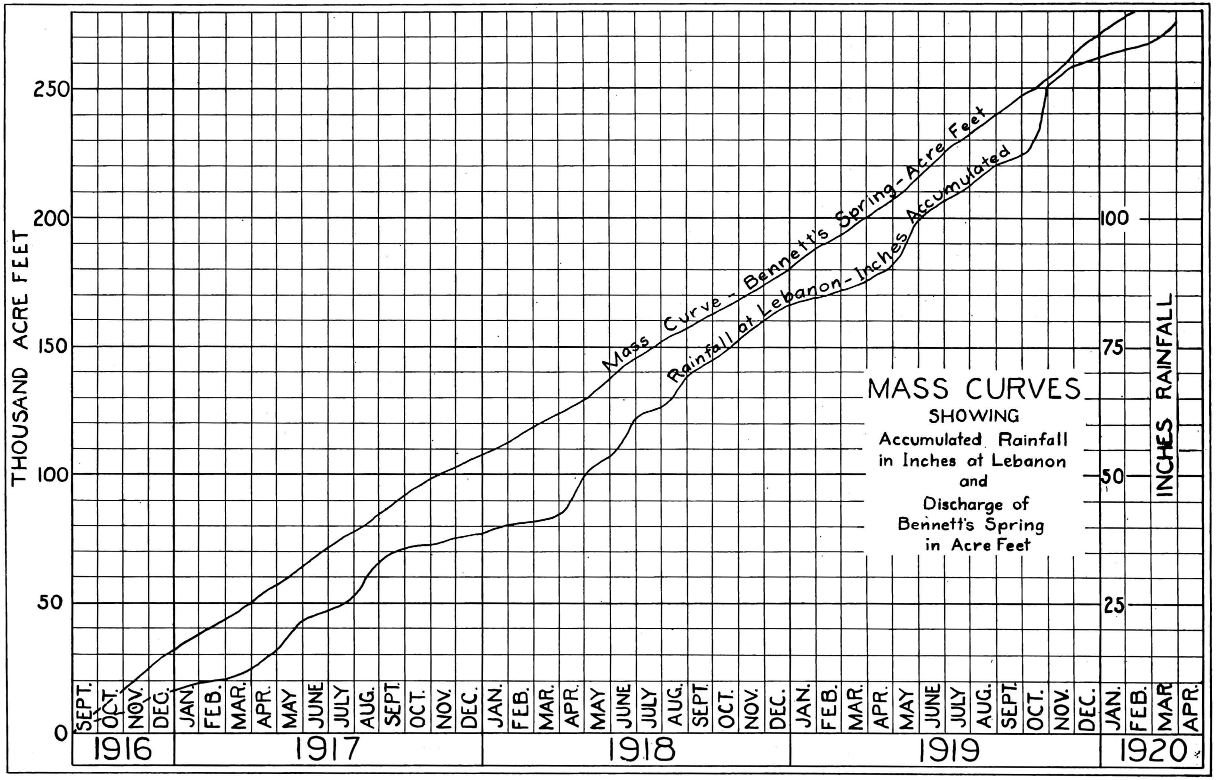
The temperature of the water flowing from Bennett's Spring is practically 59° Fahr. the year around. Measurements taken in August indicate the same water temperature as those taken in March. The temperature of the water from all of the large Ozark springs which have been observed runs uniformly between 58° and 60°.

The discharge of Bennett's Spring during the period from 1916 to 1920 is presented in the tables below.

MONTHLY DISCHARGE OF BENNETT'S SPRING AT BRICE, MISSOURI, FROM SEPTEMBER 9, 1916 to MARCH 31, 1920.

Month	Discharge in second-feet			Total discharge in acre-feet	Rainfall in inches at Lebanon
	Maximum	Minimum	Mean		
1916					
September	138	138	138	8,200	2.43
October	138	138	138	8,460	1.55
November	138	124	133	7,900	2.69
December	130	111	118	7,240	1.46
Part Year	138	111	132	31,800	8.13
1917					
January	138	96	107	6,560	1.58
February	96	96	96	5,310	0.33
March	120	96	103	6,430	2.29
April	......	......	113	6,700	3.49
May	148	113	124	7,600	5.83
June	168	101	126	7,500	1.70
July	103	91	99	6,070	2.69
August	120	91	113	6,940	7.06
September	168	91	124	7,360	2.74
October	106	89	95	5,830	0.48
November	114	83	88	5,250	1.36
December	77	69	75	4,600	1.00
The Year	168	69	105	76,150	30.55

PLATE IV.

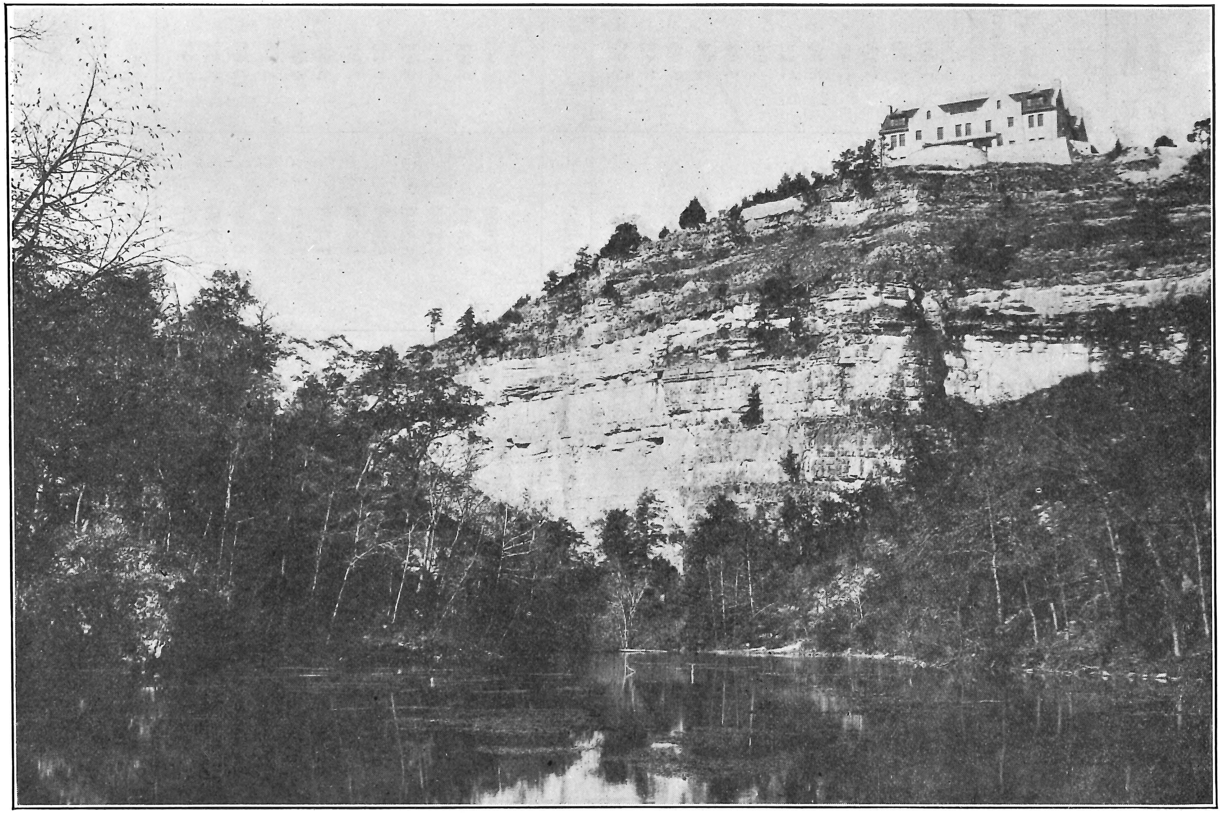


Mass Curve—Bennett's Spring

MONTHLY DISCHARGE OF BENNETT'S SPRING AT BRICE, MISSOURI, FROM SEPTEMBER 9, 1916 to MARCH 31, 1920.

Month	Discharge in second-feet			Total discharge in acre-feet	Rainfall in inches at Lebanon
	Maximum	Minimum	Mean		
1918					
January	87	74	78	4,800	1.48
February	142	73	113	6,260	0.70
March	87	77	84	5,150	1.15
April	142	77	90	5,340	7.98
May	162	128	144	8,850	3.90
June	142	89	122	7,230	7.24
July	142	87	107	6,560	1.94
August	114	77	84	5,150	5.96
September	114	87	95	5,640	3.34
October	87	87	87	5,350	3.95
November	142	87	95	5,640	4.12
December	142	100	112	6,880	2.69
The Year	162	73	101	72,850	44.45
1919					
January	142	100	119	7,300	Trace
February	142	87	100	5,540	2.69
March	133	104	116	7,110	2.01
April	119	91	105	6,240	3.05
May	149	133	141	8,650	9.10
June	164	164	164	9,750	3.27
July	119	119	119	7,300	2.88
August	119	119	119	7,300	4.03
September	119	111	114	6,780	1.79
October	111	111	111	6,800	13.83
November	164	149	154	9,150	3.57
December	164	104	127	7,800	1.97
The Year	164	87	124	89,720	48.19
1920					
January	164	91	107	6,570	1.58
February	133	104	109	6,260	1.39
March	164	104	125	7,670	4.37
Part Year	164	91	114	20,500	7.34

Plate V.



Hahatonka Spring [Photo by J. K. Wright]

Big Blue Spring.—This spring is in the northwest corner of Laclede County. It is on the east bank of the Niangua River, and is approximately nine miles in a direct line north from Bennett's Spring. The spring flows vertically from a pool at the foot of a bluff. Its source is only three feet above the ordinary low-water stage of the river, and is subject to frequent overflow from backwater. The discharge of the spring measured on July 1, 1913, was 23.2 cubic feet per second, or 15,000,000 gallons per day.

Hahatonka Spring.—The second largest of the springs on the Niangua is Hahatonka Spring, formerly known as Gunter Spring. This spring is in Camden County, eighteen miles north and five miles east of Bennett's Spring. It issues from the foot of a precipitous bluff 250 feet high, flows in a swift current thru a narrow rugged canyon for a distance of nearly 1,000 feet, and then forms a lake of about forty acres in the valley of the Niangua. The total length of the course traveled by the spring branch on its way to the Niangua River is about three-fourths of a mile. The fall from the head of the spring to the river is approximately eighteen feet.

This spring is noted for its remarkable scenic beauty and the picturesque grandeur of the country about it. The illustration, page 20, presents clearly something of the remarkable beauty of the deep gorge out of which the spring flows.

The flow of the spring measured at a point near its discharge into the river on July 4, 1913, was 53.54 cubic feet per second, equivalent to 34,600,000 gallons per day.

SPRINGS OF THE CURRENT RIVER VALLEY

Alley Spring.—The springs on the southern slope of the Ozark hills are equally as important in every respect as those already mentioned on the northern slope. Alley Spring is five miles west of Eminence in Shannon County, on Jack's Fork, a tributary of Current River. It issues from the foot of a bluff 150 feet high, forming a very beautiful pool about one acre in extent and very deep and clear. From this pool its waters pass over a 12-foot falls, there driving the water turbine of a mill. From this point it flows in a swift course a half mile to join the waters of Jack's Fork. This spring (See Fig. 2, page 15) is capable of developing 80 horse power at the mill. The power at the fall is used for operating a sawmill, a flour and gristmill, and for driving an electric generator which furnishes current for lighting and domestic use at the village of Alley. The measured flow of the spring on August 23, 1912, was 75 cubic feet per second, equivalent to 48,500,000 gallons per day.

Big Spring.—This spring is one of the largest of any of the springs observed in these investigations up to the present time. It is at the foot of a high bluff on the west side of the Current River valley, and about four miles below Van Buren, in Carter County. The spring issues with great swiftness from cavernous holes in the rock at the base of the cliff. (See Fig. 1, page 23.) The water flows rapidly in a channel about 100 feet wide which runs due east 1,000 feet to Current River. Unfortunately, the level of the head of this spring is only about six feet above the mean stage of the river, and consequently is of little value for power development. It is subject to frequent overflow from high-water of the river. Careful measurements of the flow were made on August 27, 1912. The discharge was 345 cubic feet per second, equivalent to 223,000,000 gallons per day.

SPRINGS OF THE GASCONADE RIVER VALLEY

Waynesville Spring.—This spring is near Waynesville in Pulaski County, on the east bank of the Roubidoux River, a tributary of the Gasconade. The spring issues from a small pool at the foot of a high bluff. The discharge of the spring measured on August 11, 1914, was 12 cubic feet per second, equivalent to 7,750,000 gallons per day.

Bartlett's Mill Springs.—A remarkable group of five springs is found on the bank of the Gasconade River, in Pulaski County, 7 miles northwest of Waynesville. These springs all occur within a distance along the river of three-fourths of a mile. Bartlett's Mill is supplied with power from the first of these springs. Its measured flow on August 4, 1914, was 12.2 cubic feet per second or 7,900,000 gallons per day.

Creasy Spring.—This spring is the second one of this group and is on the north side of the river one-fourth of a mile above Bartlett's Mill. Its discharge on August 14, 1914, was 20.6 cubic feet per second, or 13,300,000 gallons per day.

The three other springs of this group are about 200 yards above Creasy Spring. Two of them issue from gravel beds in the river channel and the third is at the foot of the cliff just off the south bank of the river. The total discharge of these three springs is estimated to be approximately 25 cubic feet per second, equivalent to 16,000,000 gallons per day.

SPRINGS OF BLACK RIVER VALLEY

The springs on Black River are numerous. The ordinary low-water flow of this stream is due principally to the supply from springs. None of the springs in this watershed is so great in size as some of those found in the Current River and Niangua Valleys. They are of importance, however, in that they materially influence the discharge of Black River.

PLATE VI.

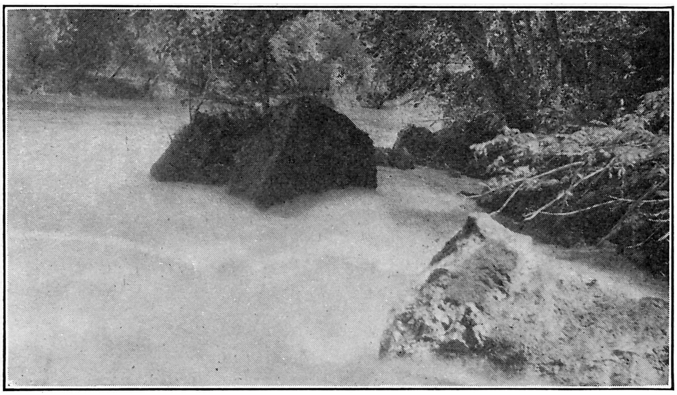


Fig. 1. Big Spring, on Current River

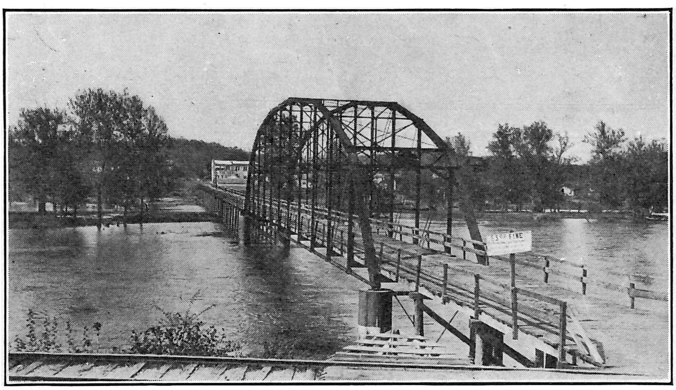


Fig. 2. Gaging Station on Current River

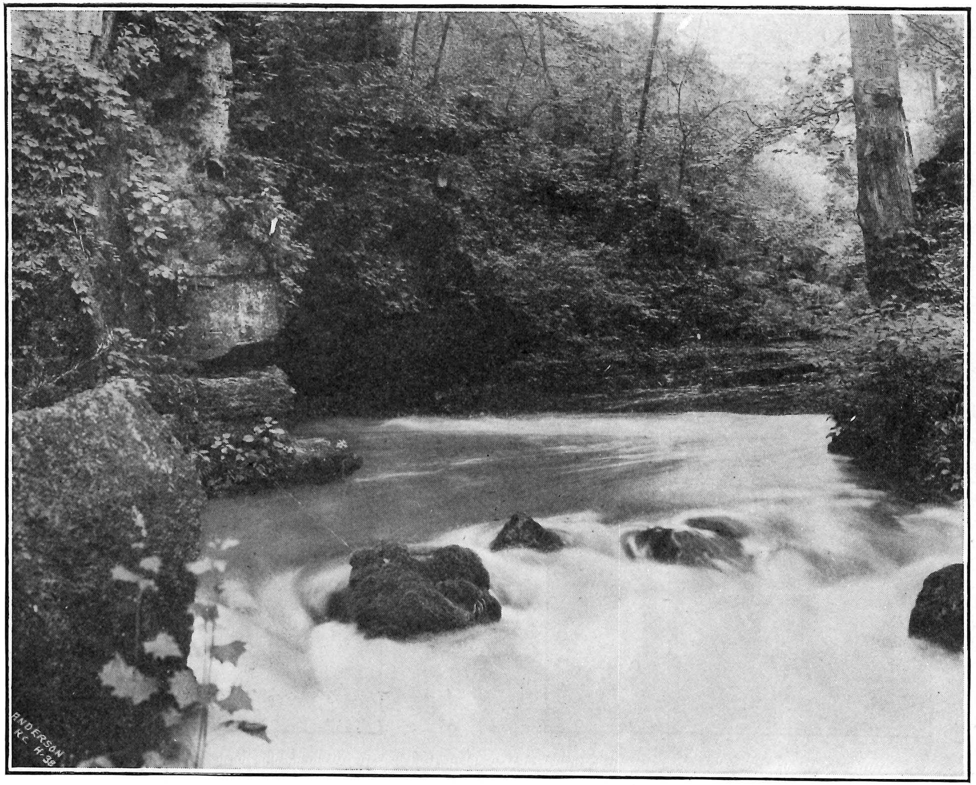


PLATE VII. **Upper Greer Spring**

Keener Spring.—This spring is at the foot of the cliff on the west bank of Black River, in Butler County, near the town of Keener. It formerly supplied the water for operating a small mill at this place. The discharge of this spring measured on August 18, 1913, was 14 cubic feet per second, equivalent to 9,000,000 gallons per day.

Mill Springs.—This spring issues from the foot of the bluff on the east side of the valley, about one-fourth of a mile below the village of the same name. It furnishes power for a water wheel which operates a pump for supplying a railway tank. Its estimated flow is 10 cubic feet per second, or 6,440,000 gallons per day.

OTHER NOTABLE SPRINGS OF THE OZARKS

Greer Spring.—One of the most remarkable of all the great springs of the Ozark region is Greer Spring, in Oregon County, near Eleven Point River. Considered from the standpoint of both quantity of discharge and rugged beauty of the gorge out of which it flows, it is not surpassed by any of the springs of the entire Ozark region. The illustrations (Pages 24, 26, and 27)* show something of the beauty of this magnificent spring and its surroundings.

The discharge of Greer Spring measured with the current meter on July 30, 1919, was 338 cubic feet per second, or 220,000,000 gallons per day.

The spring flows approximately one and three-fourths miles thru a rather precipitous gorge which is deeply eroded in lime rock. At its outlet from the gorge it joins Eleven Point River. The spring branch has a fall in its upper reaches of about 50 feet to the mile. The total fall in its run to the river is 72 feet.

The spring, with its large volume of flow and rapid fall, offers excellent opportunity for water power development. It would be difficult to determine, however, whether the magnificent beauty of the spring should be sacrificed for the commercial value of its power. Perhaps by judicious selection of the site for the power development and with attention given to the attractiveness of design of the power house and the dam, both the beauty of the spring and the usefulness of the power may be conserved.

Meramec Spring.—This beautiful spring is in Phelps County, about six miles southeast of St. James. It issues from a circular pool about 100 feet in diameter, at the base of a precipitous rock cliff. It flows northward from this pool, forming a charming spring brook of considerable size (See Figs. 1 and 2, page 28) and finally enters the

*Photos by Missouri Iron & Steel Corporation, St. Louis, Mo., owners of the spring.

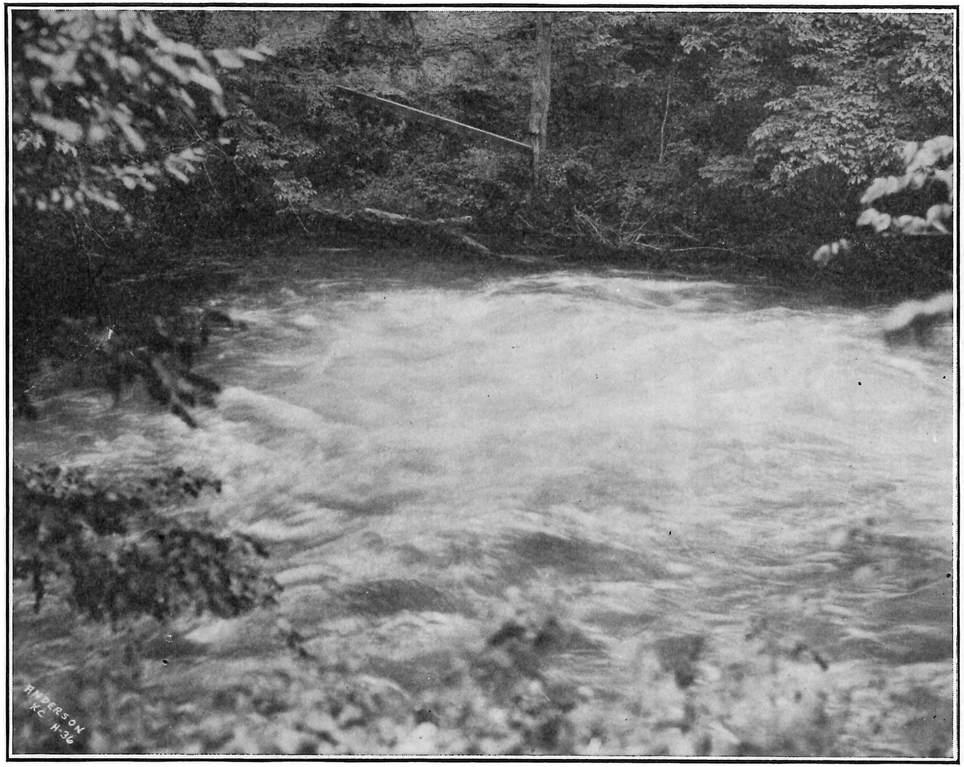


PLATE VIII. **Lower Greer Spring**

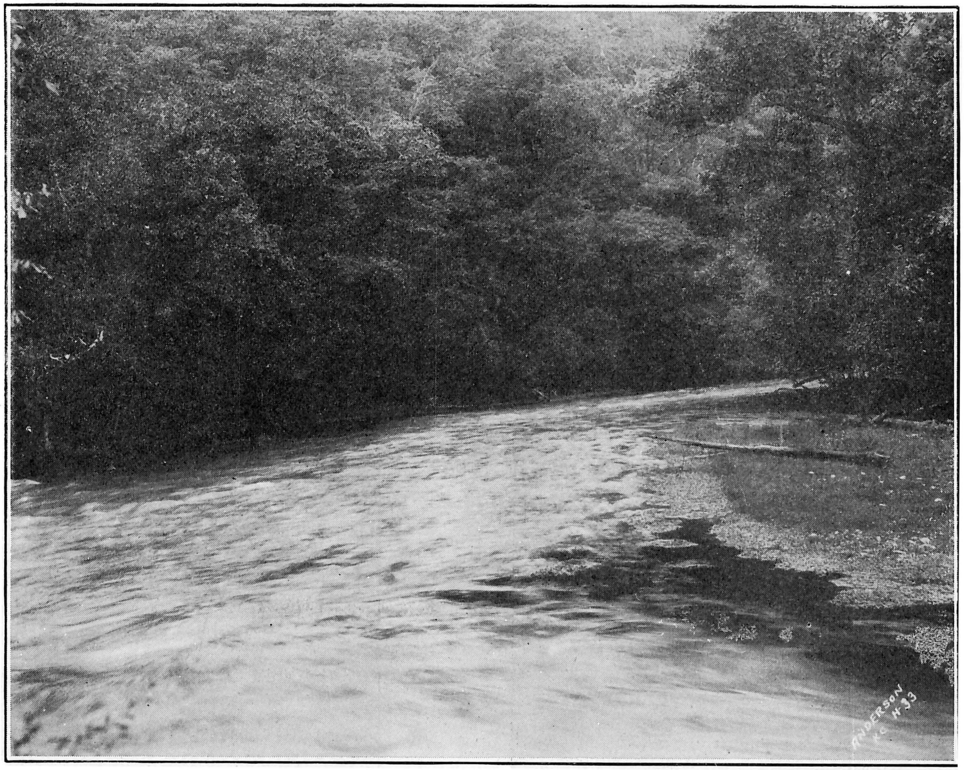


PLATE IX. **Greer Spring Rapids**

PLATE X.

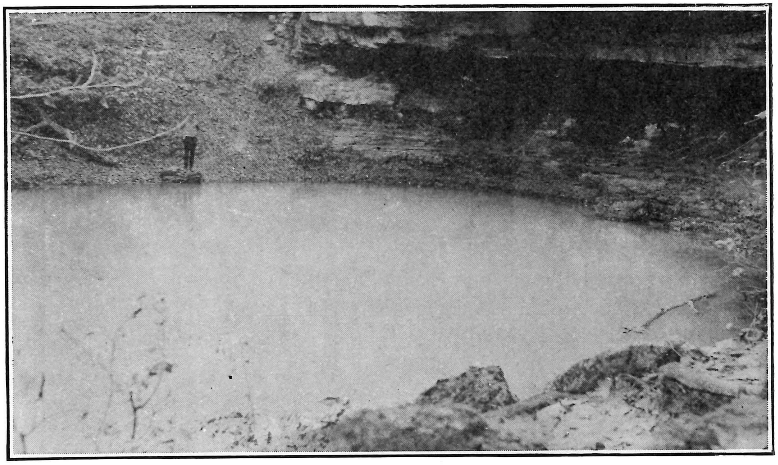


Fig. 1. Meramec Spring

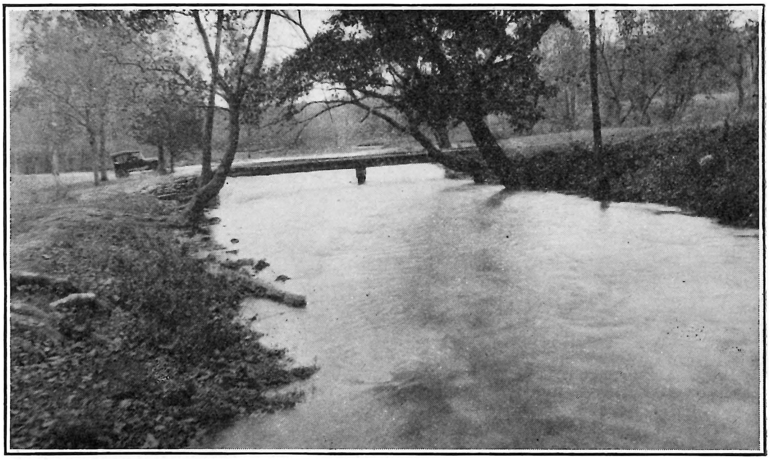


Fig. 2. Meramec Spring Branch

Meramec River, furnishing this stream with its principal head-water supply.

The temperature of the spring water was 58° and measurement of the flow of the spring with a Price current meter on October 16, 1920, was 136 cubic feet per second, or 88,000,000 gallons per day.

Double Springs.—This spring is located on the west side of the narrow valley of North Fork River, which flows thru the rugged hills of the eastern part of Ozark County. It is in Section 18, township 23 North, Range 11 West, about 20 miles west of West Plains and 31 miles south of Mountain Grove.

The spring issues with a great rush from holes in the bed-rock at the base of the bluff along the west side of the river. The water of the spring is divided into two brooks, one flowing to the south, the other to the north. From this division of flow the spring gets the name "double." The headwaters of the spring are about 8 feet above the level of the river.

The temperature of the spring water was 60°. Measurement of the flow of the spring was made August 8, 1919. The discharge was 136 cubic feet per second, or 88,000,000 gallons per day.

GENERAL FEATURES OF OZARK STREAMS

(See Frontispiece for Typical Topography)

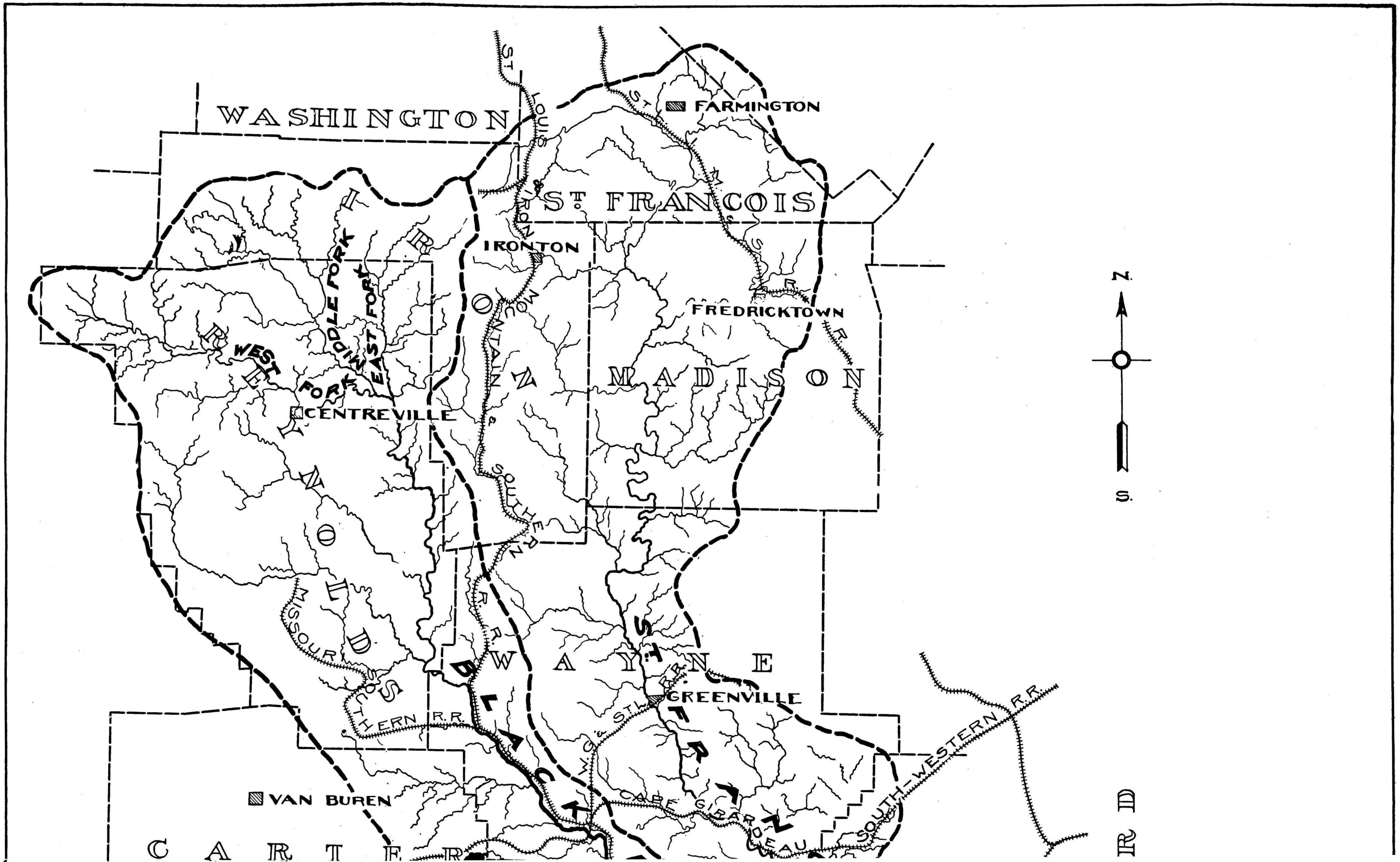
Most of the larger streams of south Missouri have their headwaters near the divide which traverses the Ozark Region from east toward the west and southwest.* The highest elevation along the divide is 1,800 feet, at Taum Sauk, in Iron County. At Cedar Gap, in Wright County, the elevation is 1,700 feet. Between these points the elevation along the divide is from 1,200 to 1,600 feet. The general topography is somewhat more rugged and rough along the streams flowing south from the divide than on those flowing north. The valleys are deeply eroded in limestone rock. The hills along the water courses rise abruptly 200 to 500 feet above the river valleys.

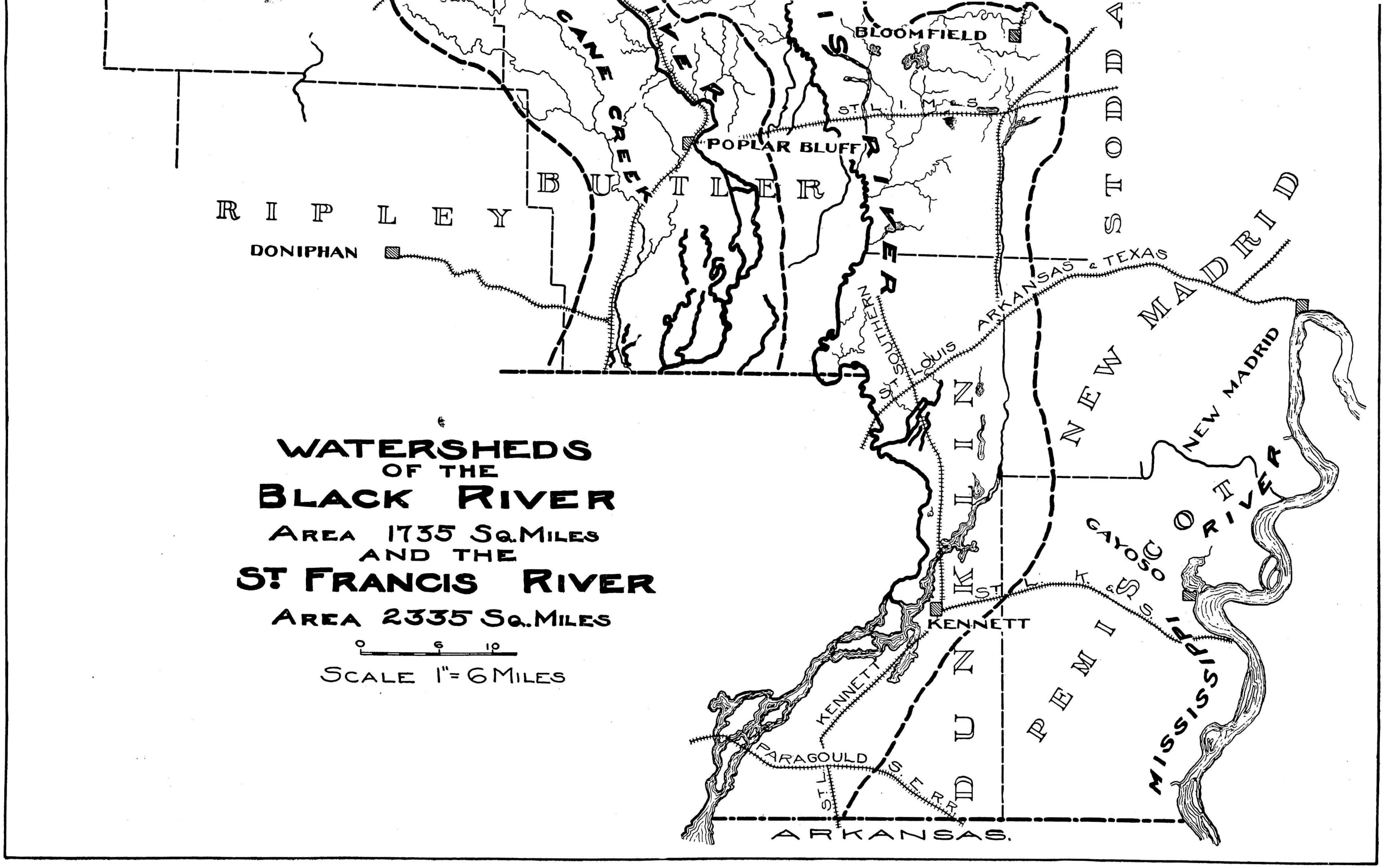
CURRENT RIVER

This stream is typical of those occurring in the more rugged portions of the Ozark hills. It has its headwaters in Texas, Shannon, and Dent Counties at an elevation of from 1,200 to 1,500 feet above sea level. Most of the watershed is forested, there still remaining in Shannon County considerable areas of oak and pine timber. A large part of the lands

*A full description of the geology of this region will be found in Water Supply Paper No. 114, U. S. Geological Survey.

PLATE XVII.


WASHINGTON
ST. FRANCOIS
FARMINGTON
IRONTON
FREDRICKTOWN
MADISON
IRON
REYNOLDS
CENTREVILLE
WEST FORK
MIDDLE FORK
EAST FORK
WAYNE
GREENVILLE
VAN BUREN
CARTER
BLACK
ST. LOUIS & IRON MOUNTAIN & SOUTHERN R.R.
MISSOURI SOUTHERN R.R.
CAPE GIRARDEAU
SOUTH-WESTERN R.R.
N.
S.


WATERSHEDS
OF THE
BLACK RIVER
AREA 1735 SQ. MILES
AND THE
ST. FRANCIS RIVER
AREA 2335 SQ. MILES
0 6 10
SCALE 1" = 6 MILES
BLOOMFIELD
POPLAR BLUFF
DONIPHAN
KENNETT
RIPLEY
BUTLER
STODDARD
NEW MADRID
DUNKLIN
PEMISCOT
CANE CREEK
ST. L. I. M. & S.
ST. LOUIS SOUTHERN
ST. LOUIS ARKANSAS & TEXAS
ST. L. K. & S.
KENNETT
PARAGOULD S. E. R.R.
GAYOSO
MISSISSIPPI RIVER
ARKANSAS.

along the lower reaches of the river has been cut over and is at present covered with second-growth timber.

Jack's Fork.—The principal tributary of Current River is Jack's Fork. This stream heads in the higher elevations of Texas County. It flows in a deeply eroded valley thru a very rugged country, and its flow is augmented by many springs all along its course, the largest of which is Alley Spring. Jack's Fork is a typical water-power stream. Its flow at low-water stage above Alley Spring is approximately 150 second feet. Below the spring the low-water flow is 225 second feet. Favorable conditions for the construction of reservoirs for storage are found at many points along this stream.

Current River Watershed.—The upper reaches of Current River are very similar in their topography to those of Jack's Fork. The main valley of Current River has a southerly course. The entire watershed of this river lies in a country of rough topography. The general fall of the river is from two to five feet to the mile. Its current is generally swifter than that of other Ozark streams. The drainage basin is fan-shaped in its upper end, where it is about fifty miles in width. The lower portion of the basin in Missouri is only about ten miles wide. The total length of that part of the watershed lying in Missouri is approximately 90 miles. The area of this watershed is 2,755 square miles. The lower part of the river is navigable for small craft except at very low stages.

The mean annual rainfall on the watershed and vicinity is about 45 inches. The winters are mild, and there is very little ice formed on the river. The waters are kept relatively warm in winter by the large inflow from springs.

The Current River basin affords a number of favorable sites for storage, both in the head waters and in the main river below. Considerable areas of land would be overflowed, but the cost of the land at present would not be prohibitive. The width of the valley from the bluffs on either side ranges generally from 1,000 to 3,000 feet. In the upper reaches of the watershed the valley is much narrower, measuring frequently only 300 to 500 feet wide.

Gaging Station.—A gaging station was located at the highway bridge at Van Buren (See Fig. 2, page 23) on August 25, 1912. Daily stages of the river are observed by means of a tape and weight suspended from the bridge. Discharge measurements are taken with a current meter by means of a boat or by wading. At high-water stages the measurements are made from the upper side of the bridge. During high-water stages the tubular piers of the bridge and the trestle of the approach to the bridge interfere with the accuracy of the measurements.

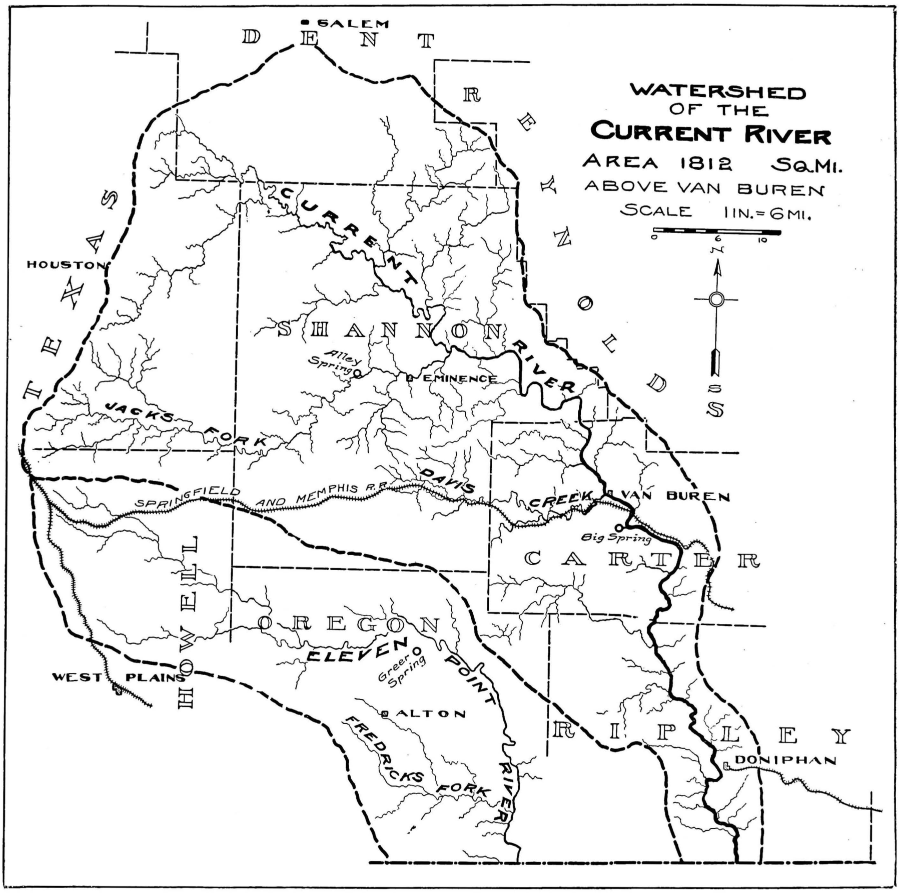

WATERSHED
OF THE
CURRENT RIVER
AREA 1812 SQ. MI.
ABOVE VAN BUREN
SCALE 1 IN. = 6 MI.
SALEM
DENT
REYNOLDS
TEXAS
SHANNON
CARTER
HOWELL
OREGON
RIPLEY
HOUSTON
CURRENT RIVER
Alley Spring
EMINENCE
JACKS FORK
DAVIS CREEK
SPRINGFIELD AND MEMPHIS R.R.
VAN BUREN
Big Spring
ELEVEN POINT RIVER
Greer Spring
ALTON
FREDRICKS FORK
WEST PLAINS
DONIPHAN
N
S

PLATE XI.

The records are reliable and accurate for all ordinary and low-water stages of the river.

The monthly discharge from September, 1912, to December, 1920, is presented in the table which follows on page 35.

RAINFALL ON CURRENT RIVER WATERSHED

Mean Annual Rainfall.—The mean annual rainfall for twenty years on Current River watershed and adjacent territory is estimated to be 45.13 inches. This value is the mean of five stations taken from the records of the U. S. Weather Bureau. The stations are Birchtree, Doniphan, Koshkonong, Poplar Bluff, and Olden. The first two of these stations, Birchtree and Doniphan, are within the Current River watershed. Two of the other stations are to the west of this watershed, the other to the east. It is believed that the average from these stations represents fairly well the rainfall distribution on this watershed.

Minimum Rainfall.—The lowest annual rainfall on this watershed within the period of the last 27 years, 1894 to 1920, was 25.02 inches. This occurred in 1901. The rainfall for that year was notably short over the entire state of Missouri. The total precipitation on the Current River watershed for fourteen consecutive months, from December, 1900, to January, 1902, inclusive, was only 28.77 inches, a shortage below the normal for this period of 22.63 inches. Such an extreme variation from the normal rainfall is quite certain to produce a material reduction in the yield or run-off from this watershed. Observations in this region have not been made for a sufficient length of time to establish satisfactorily the effect of unusual dry weather on the rate of run-off.

The amount of the monthly and annual rainfall, covering the period in which observations on run-off on Current River were made, has been tabulated for comparative study, and appears in the table on page 35 of this report.

MONTHLY DISCHARGE OF CURRENT RIVER AT VAN BUREN, MISSOURI, FROM AUGUST 25, 1912, to NOVEMBER 30, 1920

(Drainage area, 1,812 square miles)

Month	Discharge in second-feet				Rainfall in inches on drainage area	Run-off	
	Maximum	Minimum	Mean	Mean per sq. mi.		Depth in inches on drainage area	Total in acre-feet
1912							
September	1,250	680	730	0.403	3.99	0.448	43,300
October	750	660	700	.386	3.82	.443	42,800
November	850	660	730	.403	1.61	.448	43,300
December	750	660	690	.381	0.83	.438	42,300
Part Year	1,250	660	711	0.392	10.25	1.777	171,700
1913							
January	9,100	670	2,280	1.257	7.94	1.449	140,000
February	1,250	780	950	.524	2.00	.545	52,700
March	11,500	750	1,986	1.096	4.82	1.262	122,000
April	3,150	1,580	2,320	1.280	3.08	1.428	138,000
May	1,000	690	800	.442	0.97	.507	49,000
June	750	640	740	.386	2.50	.429	41,500
July	870	590	700	.386	3.28	.443	42,800
August	605	550	600	.331	1.59	.380	36,700
September	740	540	600	.331	7.69	.368	35,600
October	3,200	560	948	.523	6.99	.603	58,300
November	2,400	710	948	.523	3.88	.583	56,300
December	1,780	780	961	.530	2.35	.612	59,900
The Year	11,500	540	1,151	0.635	47.09	8.609	831,900

MONTHLY DISCHARGE OF CURRENT RIVER AT VAN BUREN, MO., 1912-1920—Continued.

Month	Discharge in second-feet				Rainfall in inches on drainage area	Run-off	
	Maximum	Minimum	Mean	Mean per sq. mi.		Depth in inches on drainage area	Total in acre-feet
1914							
January	1,050	700	760	0.419	2.19	0.482	46,600
February	10,420	700	2,574	1.420	3.74	1.476	142,700
March	1,410	840	1,050	.579	3.03	.666	64,300
April	36,000*	1,030	2,396	1.322	6.14	1.475	142,500
May	7,900	1,060	2,090	1.154	2.23	1.326	128,140
June	1,520	730	1,000	.552	0.32	.621	60,000
July	890	840	850	.469	1.66	.538	52,000
August	930	840	850	.469	5.17	.538	52,000
September	14,000	840	1,426	.787	5.85	.876	84,690
October	1,730	840	1,050	.579	2.56	.666	64,300
November	830	790	808	.446	0.76	.497	48,000
December	2,180	900	1,266	0.698	3.32	.803	77,600
The Year	36,000*	700	1,335	0.738	36.97	9.964	962,930
1915							
January	10,222	1,000	1,420	0.783	3.62	0.903	87,100
February	13,618	2,180	4,305	2.378	3.43	2.390	239,000
March	5,416	1,000	2,126	1.173	1.33	1.347	130,800
April	5,305	1,100	1,670	0.923	2.16	1.048	99,000
May	26,600	875	3,658	2.018	6.58	2.328	224,200
June	9,607	1,955	3,811	2.110	6.74	2.340	226,000
July	4,150	1,500	1,897	1.048	1.88	1.206	116,400
August	125000*	1,550	9,600	5.300	14.30	6.165	588,000
September	1,900	890	1,033	0.573	1.98	0.638	61,300
October	900	820	851	0.473	1.32	0.545	52,200
November	4,000	800	938	0.522	3.64	0.581	55,700
December	1,550	890	1,109	0.616	3.43	0.709	68,000
The Year	125,000	800	2,690	1.500	50.41	20 200	1947,700

*Estimated.

MONTHLY DISCHARGE OF CURRENT RIVER AT VAN BUREN, MO., 1912-1920—Continued.

Month	Discharge in second-feet				Rainfall in inches on drainage area	Run-off	
	Maximum	Minimum	Mean	Mean per sq. mi.		Depth in inches on drainage area	Total in acre-feet
1916							
January	85,000*	1,100	6,650	3.800	8.58	4.250	408,000
February	35,000	1,160	8,300	4.610	1.12	4.820	462,000
March	1,400	1,000	1,149	0.638	2.32	0.734	70,300
April	7,300	1,100	2,762	1.535	4.18	1.710	164,000
May	1,260	900	1,034	0.574	3.09	0.662	63,400
June	3,600	890	1,126	0.625	4.89	0.698	66,900
July	900	810	839	0.467	0.51	0.537	51,500
August	900	810	831	0.462	2.78	0.532	51,000
September	820	800	810	0.450	3.98	0.502	48,100
October	815	800	805	0.436	1.67	0.515	49,300
November	860	800	808	0.449	2.73	0.501	48,000
December	1,280	800	890	0.494	3.67	0.570	54,600
The Year	85,000	800	2,120	1.179	39.52	16.031	1537,100
1917							
January	6,300	800	1,129	0.627	2.96	0.722	69,200
February	800	790	793	0.442	0.45	0.461	45,200
March	900	760	805	0.447	2.08	0.516	49,300
April	7,700	1,000	2,919	1.620	8.41	1.807	173,000
May	6,200	1,010	1,707	0.947	3.84	1.093	104,700
June	7,600	860	1,910	1.061	4.39	1.182	113,200
July	1,010	790	830	0.461	3.90	0.531	50,800
August	6,800	750	1,020	0.567	8.12	0.653	62,600
September	860	690	717	0.398	1.87	0.443	42,500
October	800	690	700	0.389	1.45	0.448	42,800
November	3,100	690	820	0.456	2.52	0.508	48,700
December	1,040	690	735	0.408	1.06	0.471	45,200
The Year	7,700	690	1,170	0.650	41.07	8.835	847,200

*Estimated.

MONTHLY DISCHARGE OF CURRENT RIVER AT VAN BUREN, MO., 1912-1920—Continued.

Month	Discharge in second-feet				Rainfall in inches on drainage area	Run-off	
	Maximum	Minimum	Mean	Mean per sq. mi.		Depth in inches on drainage area	Total in acre-feet
1918							
January	700	700	700	0.389	2.94	0.447	42,900
February	4,400	690	1,220	0.673	0.76	0.706	67,700
March	770	600	720	0.400	0.81	0.461	44,200
April	10,700	700	2,557	1.420	6.83	1.580	151,500
May	29,000	780	6,300	3.500	6.39	4.020	386,000
June	2,100	1,400	1,580	0.877	3.47	0.977	93,800
July	1,610	1,440	1,490	0.828	1.58	0.950	91,200
August	2,400	820	1,120	0.622	4.34	0.715	68,600
September	1,400	780	1,034	0.574	4.23	0.639	61,300
October	2,600	710	910	0.506	2.87	0.582	55,800
November	1,400	730	925	0.514	2.95	0.580	55,000
December	6,600	830	1,535	0.852	4.09	0.982	94,100
The Year	29,000	690	1,675	0.930	41.26	12,639	1212,100
1919							
January	1,370	850	1,004	0.559	0.45	0.642	61,600
February	1,580	830	971	0.539	1.94	0.562	54,000
March	2,500	880	1,100	0.611	2.13	0.692	66,300
April	920	680	769	0.427	1.97	0.476	45,700
May	2,600	1,300	1,726	0.954	5.08	1.103	105,800
June	16,000	1,420	3,450	1.905	6.86	2.130	204,500
July	1,500	830	1,071	0.592	1.27	0.683	65,600
August	830	730	783	0.433	2.70	0.500	48,000
September	1,430	680	853	0.461	2.69	0.538	49,400
October	2,000	680	926	0.456	8.88	0.591	56,800
November	9,400	640	2,800	1.546	4.14	1.730	166,000
December	920	780	844	0.467	0.40	0.538	51,700
The Year	16,000	640	1,350	0.745	38.51	10.185	975,400

MONTHLY DISCHARGE OF CURRENT RIVER AT VAN BUREN, MO., 1912-1920—Continued.

Month	Discharge in second-feet				Rainfall in inches on drainage area	Run-off	
	Maximum	Minimum	Mean	Mean per sq. mi.		Depth in inches on drainage area	Total in acre-feet
1920							
January	3,500	770	1,163	0.643	3.11	0.742	71,200
February	1,380	770	1,130	0.623	1.08	0.675	64,800
March	22,900	770	5,673	3.135	5.98	3.625	348,000
April	6,800	760	2,334	1.287	2.88	1.442	138,600
May	7,700	2,180	4,406	2.435	6.79	2.820	270,500
June	2,380	1,450	2,082	1.150	0.80	1.287	123,600
July	2,600	1,300	1,616	0.892	2.18	1.033	99,100
August	2,400	1,150	1,419	0.783	6.25	0.906	87,000
September	3,600	920	1,847	1.020	5.83	1.141	109,600
October	2,240	920	1,081	0.597	4.42	0.691	66,300
November	1,020	970	988	0.547	1.11	0.610	58,600
December	1,500	900	1,030	1.569	2.66	0.653	63,200
The Year	22,900	760	2,070	1.143	43.09	15.625	1500,500

FLOW OF CURRENT RIVER

Maximum Flow.—The maximum flood flow of Current River during the period of eight years over which these observations extend, 1912-1920, occurred on August 21, 1915. The gage rose 25 feet above low water. The bridge on which the gage was established went out at 3:00 a. m., August 21. The distribution of the rainfall over the watershed which produced this unusual flood and its effect on the gage readings are tabulated as follows:

August 18, rainfall 2.55 inches, gage reading 0.00 feet.
August 19, rainfall 2.12 inches, gage reading 1.10 feet.
August 20, rainfall 3.70 inches, gage reading 14.60 feet
August 21, rainfall none, inches, gage reading 25.00 feet.
Total rainfall 8.37 inches in three days.

Unusually heavy rainfall occurred on August 20 at points adjacent to this watershed, 5.17 inches in 24 hours recorded at Gano near the divide of the upper headwaters of the Current River watershed, and 6.70 inches at Ironton directly east of the watershed.

A greater flood than the one recorded above occurred on March 26, 1904. It is reported that Current River at Van Buren rose 30 feet above low water stage, and that the homes of many of the people of Van Bureau were inundated. The discharge of the river at this stage of 30 feet is estimated to be approximately 165,000 cubic feet per second, equivalent to 90 cubic feet per second per square mile of drainage area. The rainfall which produced this flood averaged 4 inches over the entire watershed and occurred between sunset of March 24 and sunset of March 25.* The occurrence of such an extreme flood on this stream is rare and happens probably not oftener than once in fifty years.

Frequency of Medium Floods.—Floods of more frequent occurrence on Current River having a discharge of some 30,000 cubic feet per second with a corresponding rise on the gage of 12 to 14 feet are indicated in the records of these studies as happening as often as once in four or five years. Referring to the table of monthly discharge of Current River (page 35) will be seen that a flood discharge of 30,000 cubic feet per second or greater occurred four times in eight years at the Van Buren gaging station. The rate of discharge of these average or frequent floods is approximately 20 cubic feet per second per square mile from the catchment area of 1,812 square miles. The rainfall which produced this flood was unusual in the way in which its excessive rate was distributed rather than in the total amount which fell. The storm began on April 25 and ended on April 28. The distribution of the rainfall* at Birchtree, located near the center of the watershed, and its effect on the gage readings at Van Buren, were as follows:

April 25,	rainfall 0.36 inches,	gage reading	1.25 feet.
April 26,	rainfall 1.00 inches,	gage reading	1.55 feet.
April 27,	rainfall 1.32 inches,	gage reading	1.50 feet.
April 28,	rainfall 3.00 inches,	gage reading	3.20 feet.
April 29,	rainfall none, inches,	gage reading	12.35 feet.
April 30,	rainfall none, inches,	gage reading	7.10 feet.
May 1,	rainfall none, inches,	gage reading	4.50 feet.

Total rainfall 5.68 inches.

*U. S. Weather Bureau records.

The effect on the flow of the river of such a distribution of the rainfall is apparent from the above table. The river may be characterized as of the "flashy" type; that is, it responds quickly to rainfall conditions, both in its rise and fall.

Minimum Flow.—The minimum flow is indicated in the monthly discharge table. It occurs usually in the late summer, fall, and early winter months. The observed minimum was 540 second feet, and occurred in September, 1913. A low rate of discharge may be expected from June to February, having a duration of from six to eight months.

Mean Flow.—The mean annual or average flow of Current River during the eight years of observation was 1,684 cubic feet per second, or 0.93 cubic feet per second per square mile of drainage area. The lowest observed mean monthly flow for any one year was 1,151 cubic feet per second in 1913.

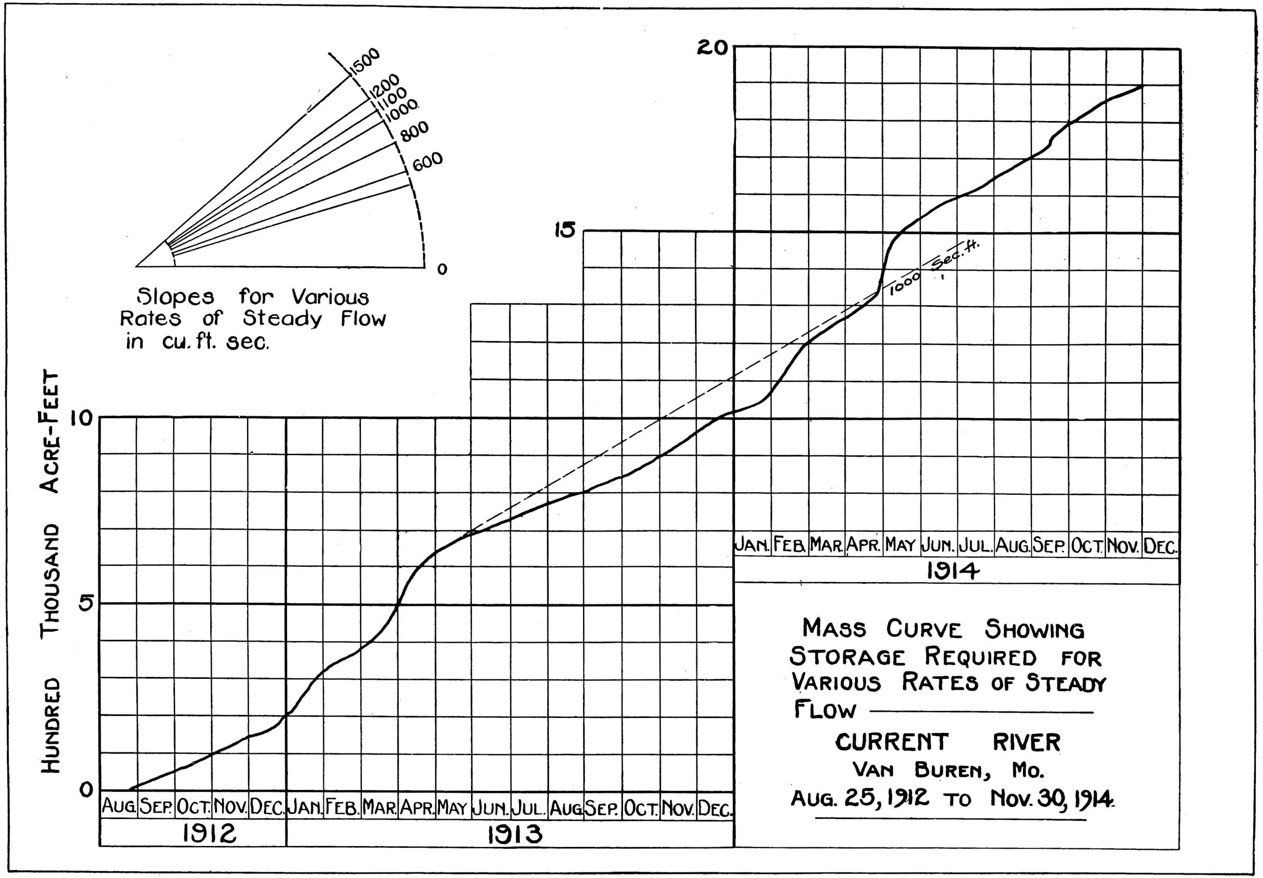
A mean annual flow of not less than 1,000 cubic feet per second may be expected at the Van Buren station. However, special attention is directed to the unusual conditions of dry weather in 1901, both as to the shortage in rainfall and the duration of these extreme conditions. This unusual rainfall condition has been discussed in this report under "rainfall." With the limited amount of information observed up to the present time it is difficult to make any satisfactory estimate of the effect of such an exended dry-weather period on the run-off of this river.

Effect of Big Spring on the Discharge.—The discharge of Current River at low-water stage, measured on August 30, 1912, near Club House, ten miles southeast of the Van Buren station, was 1,135 cubic feet per second. On the same day the discharge at Van Buren was 680 cubic feet per second. This is a very material increase in discharge for such a short distance between the two stations. This increase is explained, however, by the fact that Big Spring, located between these stations, was delivering into the river 345 cubic feet per second. The effect of this spring on the low-water discharge of the river at this point is therefore to increase it approximately from 0.43 to 0.670 cubic feet per second per square mile. This is a matter of much importance in considerations relative to power development on this stream.

WATER POWER

Stream Flow and Water Power.—The yield from a watershed and the fluctuation in this yield throughout the various seasons from year to year are perhaps the most important factors to be considered in water power studies on rivers of this type. These factors are also uncertain and difficult of determination. Other factors entering into the problem of water-power development are the head available and the storage re-

Plate XII.



1500
1200
1100
1000
800
600
0
Slopes for Various Rates of Steady Flow in cu. ft. sec.
1000 Sec. ft.
Hundred Thousand Acre-Feet
0
5
10
15
20
Aug. Sep. Oct. Nov. Dec.
1912
Jan. Feb. Mar. Apr. May Jun. Jul. Aug. Sep. Oct. Nov. Dec.
1913
Jan. Feb. Mar. Apr. May Jun. Jul. Aug. Sep. Oct. Nov. Dec.
1914
Mass Curve Showing Storage Required for Various Rates of Steady Flow
Current River
Van Buren, Mo.
Aug. 25, 1912 to Nov. 30, 1914.

quired for regulating the flow. These factors can be accurately determined by surveys. Stream flow, however, depending primarily upon rainfall over the catchment area and upon the character of the surface features, and subject to the many influences of the seasons, is more difficult of determination. A study of the rainfall conditions and of the daily discharge observed for a considerable period of time afford the principal means for reaching any sort of reliable conclusions concerning the behavior of a stream.

The Mass Curve and Storage.—To facilitate the process of determining the effect of storage on the variable daily and seasonal flow of a stream the mass curve is of great assistance. This graphical method of indicating the results, which otherwise would require long and tedious calculations to be presented in a series of tables, simplifies the problem and renders its solution comparatively easy.

The mass curve for Current River is presented on page 42. Its construction consists in adding up the daily discharge of the stream, from month to month, including the 1913 period of extreme low water, beginning, in this case, on August 25, 1912, and ending November 30, 1914. These additions, or accumulations, are then plotted for the successive months. The resulting irregular line is the mass curve. It represents at any point the total amount of water discharged by the stream from the first day or date of observation up to the time in question. For convenience the quantity of water represented by the mass curve is given in acre-feet.

In addition to the mass curve, a series of lines representing various rates of steady or uniform flow, as would be required in the operation of a water-power plant, are drawn in the upper left-hand corner of the plate.

To determine the storage necessary for any rate of steady draft at the power plant, a line parallel to the slope for that rate is drawn tangent to the mass curve at its various summits. The greatest vertical distance measured between this tangent line and the mass curve indicates the storage required for that rate of draft. This process is illustrated on the plate by the dotted line drawn parallel to a rate of steady draft of 1,000 cubic feet per second. The storage required for maintaining this steady draft on a 24-hour basis is represented by the greatest vertical space between the two lines, and is approximately 110,000 acre-feet. In a similar way the storage required for any other rate of steady draft at the power plant may be quickly determined.

Power Available.—The amount of power that can be economically developed on Current River will depend upon the capacity of suitable storage basins so located as to control the flow from a large part of the watershed. Such storage basins will require feasible sites for the construction of dams at reasonable cost and of sufficient height for creating the necessary head required for the development of power. These are factors which can be determined only by proper surveys. On the basis, however, that storage is available for controlling the flow of the river, estimates may be made on the amount of power which can be developed for any given head.

A steady flow of 1,000 cubic feet per second at the Van Buren gaging station where the drainage area is 1,812 square miles is equivalent to a yield of 0.60 cubic feet per second per square mile. Under a head of one foot and an efficiency at the power plant of eighty per cent, the power available is 0.055 continuous horse power per square mile of drainage area or approximately 100 horse power for each foot of head at the Van Buren station. With a mean head of 25 feet the power available at this point on the river would amount to about 2,500 horse power for a continuous twenty-four hour service. Estimated on the basis of service of 16 hours per day and a 50 per cent load factor the nominal capacity of the plant would be raised to approximately 7,500 horse power. The above estimates are made on the assumption of sufficient storage capacity for regulating the discharge of the river to a steady flow of 1,000 cubic feet per second, and the results should be interpreted on that basis. The total amount of power available from this stream will depend upon the location and capacity of feasible storage basins. Surveys will be required at various points along the river valley for obtaining necessary information to determine the most suitable location for dam sites and storage basins.

THE NIANGUA RIVER WATERSHED

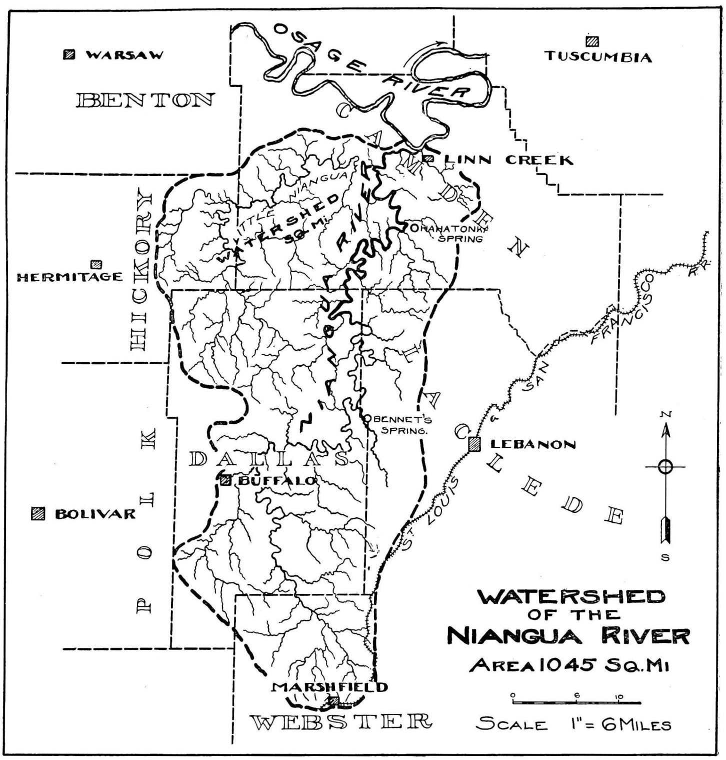
The Niangua River watershed lies on the north slope of the Ozark Plateau. Tho the general course of the Niangua valley is nearly due north, it is the most tortuous in its windings through the hills of any of the streams thus far examined. A map of this watershed is given on page 45.

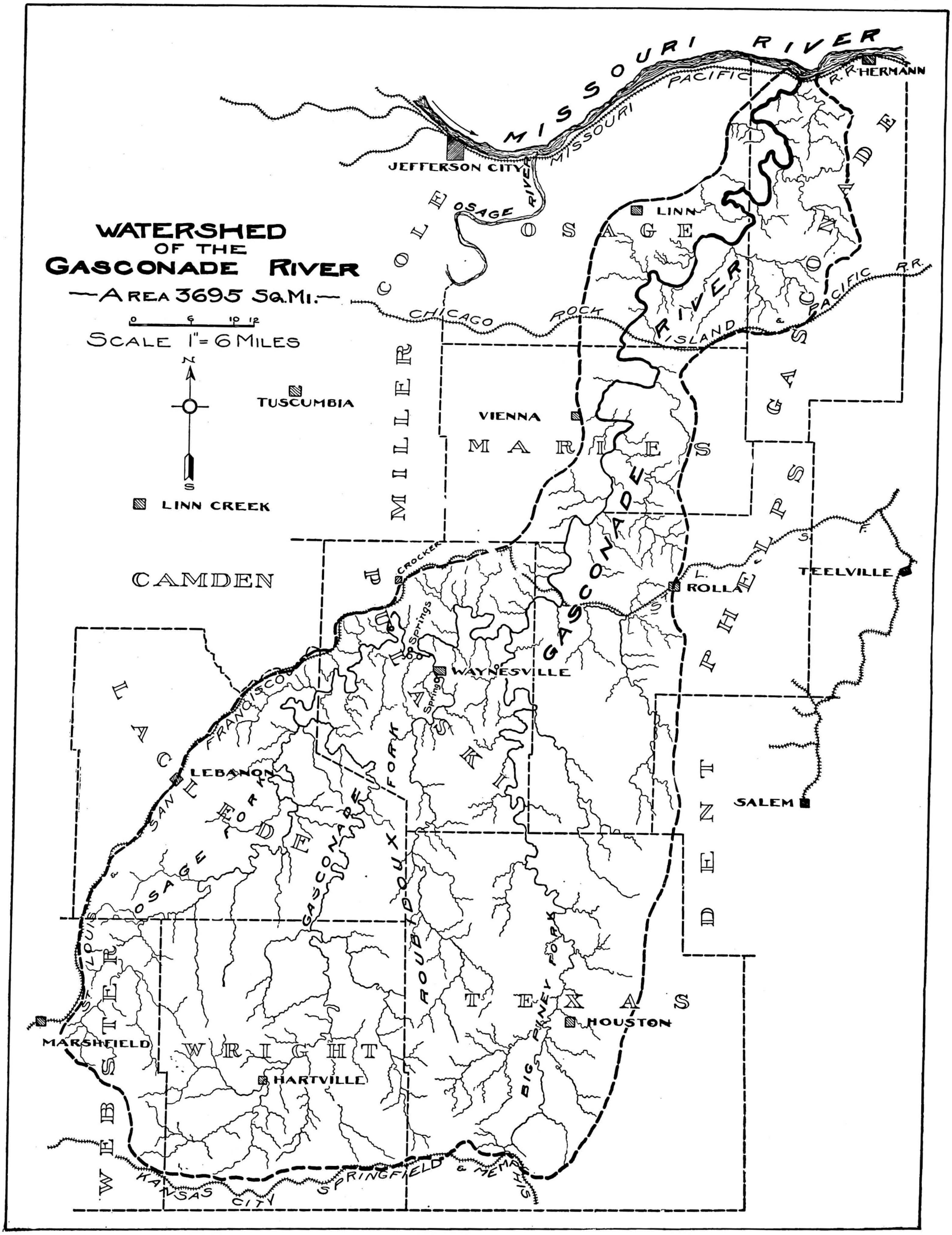
The width of the Niangua valley is approximately 1,000 to 2,500 feet. The hills rise precipitaously 150 to 400 feet on either side of the valley. Favorable sites for storage are at several points along the stream.

The low-water flow of this stream is supplied by numerous springs found all along its course. Among these are two noted springs, Bennett's and Hahatonka, described in another part of this report.

Measurements of the low-water flow of the Niangua were made July 4, 1912, near Hahatonka. The discharge was 220 cubic feet per second, indicating a low-water discharge from this watershed of approximately 0.310 cubic feet per second per square mile. The Niangua offers favorable conditions for power development.

PLATE XIII.


WARSAW
TUSCUMBIA
BENTON
OSAGE RIVER
CAMDEN
LINN CREEK
HICKORY
HERMITAGE
LITTLE NIANGUA
WATERSHED
SQ. MI.
NIANGUA RIVER
HA HA TONKA SPRING
ST. LOUIS SAN FRANCISCO R.R.
BENNET'S SPRING
LACLEDE
LEBANON
DALLAS
BUFFALO
POLK
BOLIVAR
N
S
WATERSHED
OF THE
NIANGUA RIVER
AREA 1045 SQ. MI
MARSHFIELD
WEBSTER
SCALE 1" = 6 MILES


WATERSHED
OF THE
GASCONADE RIVER
—AREA 3695 SQ.MI.—
SCALE 1" = 6 MILES
MISSOURI RIVER
MISSOURI PACIFIC R.R.
HERMANN
JEFFERSON CITY
OSAGE RIVER
COLE
LINN
OSAGE
GASCONADE
RIVER
CHICAGO ROCK ISLAND & PACIFIC R.R.
TUSCUMBIA
MILLER
VIENNA
MARIES
LINN CREEK
CAMDEN
CROCKER
PULASKI
WAYNESVILLE
ROLLA
PHELPS
TEELVILLE
ST. L. S. F.
LACLEDE
LEBANON
ST. LOUIS & SAN FRANCISCO
OSAGE FORK
GASCONADE
ROUBIDOUX FORK
DENT
SALEM
WEBSTER
MARSHFIELD
WRIGHT
HARTVILLE
TEXAS
HOUSTON
BIG PINEY FORK
KANSAS CITY SPRINGFIELD & MEMPHIS

THE GASCONADE RIVER

A preliminary examination was made of a portion of the Gasconade watershed, and a gage was established at the highway bridge on the road between Crocker and Waynesville, Pulaski County. The gage was established on August 15, 1914. Gage readings are observed daily, and measurements of the flow at low, ordinary, and high-water stages of the river have been made. The minimum discharge of this watershed at extreme low-water stage, measured on August 15, 1914, was approximately 0.118 cubic feet per second per square mile. A map of this drainage basin is presented on page 46. The general character of the topography of this watershed and the indications from the discharge measurements already taken give promise of interesting power possibilities on this river.

Monthly Discharge.—The discharge of Gasconade River from August, 1914, to December 1, 1920, is presented in tabulated form below. The maximum, minimum, and mean for each month are given, and the corresponding run-off is compared with the rainfall on the watershed.

MONTHLY DISCHARGE OF GASCONADE RIVER AT CROCKER-WAYNESVILLE BRIDGE FROM AUGUST 16, 1914, to NOVEMBER 30, 1920.

(Drainage Area, 1,800 square miles)

Month	Discharge in second-feet				Rainfall in inches on drainage area	Run-off	
	Maximum	Minimum	Mean	Mean per sq. mi.		Depth in inches on drainage area	Total in acre-feet
1914							
August	579	227	300	0.167	2.16	0.186	17,800
September	28,290	258	3,794	2.125	7.45	2.347	225,300
October	12,330	384	1,520	0.845	4.34	0.972	93,300
November	537	320	379	0.212	1.08	0.241	23,200
December	2,270	352	760	0.422	3.04	0.478	46,000
Part Year	28,290	227	1,350	0.754	18.07	4.224	405,600

MONTHLY DISCHARGE OF GASCONADE RIVER AT CROCKER-WAYNESVILLE BRIDGE, 1914-1920—Continued.

Month	Discharge in second-feet				Rainfall in inches on drainage area	Run-off	
	Maximum	Minimum	Mean	Mean per sq. mi.		Depth in inches on drainage area	Total in acre-feet
1915							
January	11,190	495	1,050	0.584	2.36	0.670	64,400
February	14,325	1,330	4,080	2.268	2.74	2.354	226,000
March	7,370	630	2,240	1.245	1.35	1.386	133,000
April	9,853	516	1,755	0.975	2.59	1.083	104,000
May	14,800	320	2,630	1.461	5.66	1.682	161,000
June	7,180	750	1,930	1.071	5.71	1.193	114,600
July	2,440	352	720	0.400	2.72	0.460	44,200
August	36,410	352	6,140	3.452	11.21	3.920	376,300
September	5,260	537	1,620	0.900	2.83	1.001	96,400
October	579	352	427	0.237	1.38	0.273	26,200
November	6,220	326	950	0.527	2.92	0.607	58,200
December	2,362	516	1,145	0.637	2.44	0.728	69,800
The Year	36,410	320	2,057	1.146	43.91	15,357	1,474,100
1916							
January	29,050	1,914	8,470	4.705	9.32	5.400	519,500
February	32,850	864	3,630	2.019	0.86	2.098	201,500
March	1,710	702	1,060	0.589	1.83	0.677	65,000
April	9,281	1,036	4,160	2.314	4.50	2.568	247,000
May	7,370	720	1,610	0.895	4.34	1.029	98,700
June	10,045	902	3,430	1.912	5.35	2.160	203,800
July	902	211	403	0.241	1.11	0.257	24,700
August	1,380	154	233	0.129	1.83	0.149	14,300
September	159	143	153	0.085	2.78	0.094	9,000
October	165	143	148	0.082	1.09	0.094	9,000
November	196	122	151	0.084	2.14	0.097	9,300
December	227	149	165	0.092	2.26	0.105	10,100
The Year	32,850	122	1,976	1.012	37.41	14.728	1,411,900

*Estimated.

MONTHLY DISCHARGE OF GASCONADE RIVER AT CROCKER-WAYNESVILLE BRIDGE, 1914-1920—Continued.

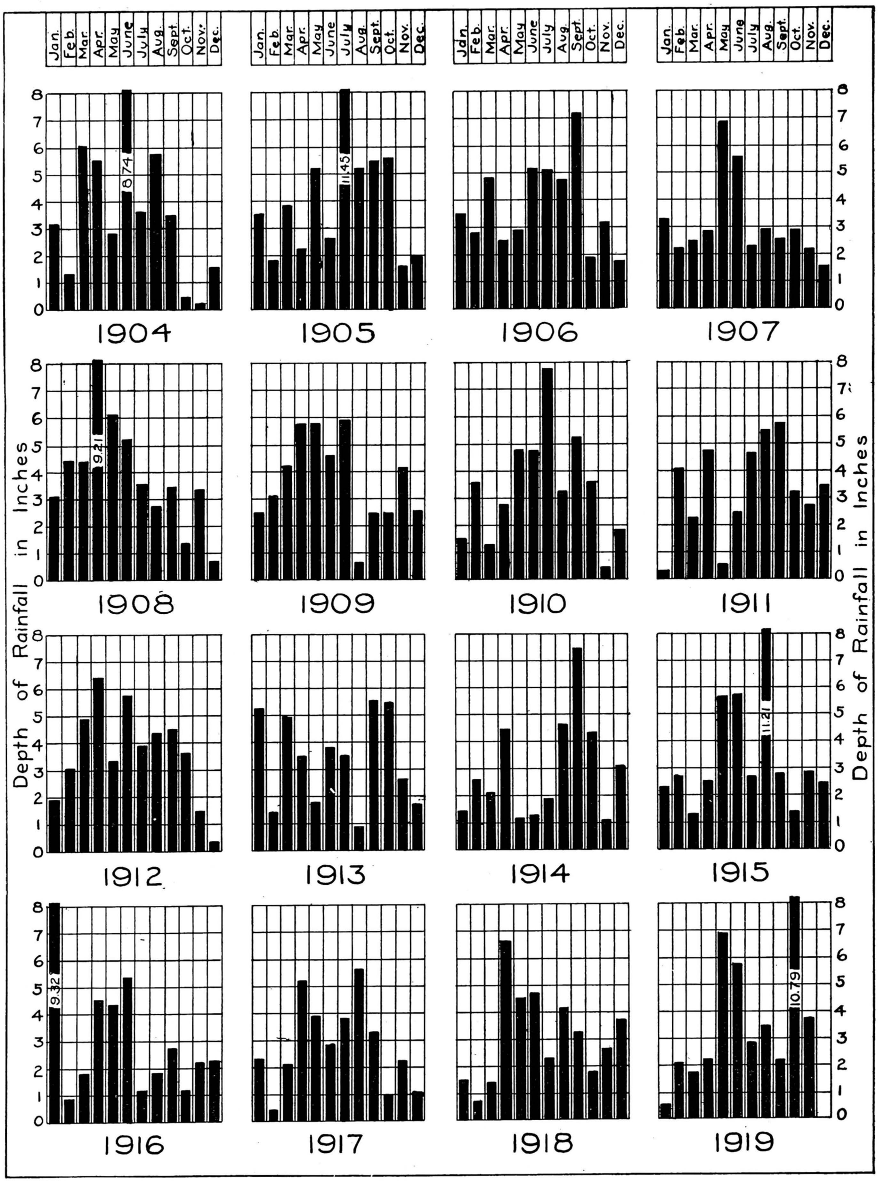
Month	Discharge in second-feet				Rainfall in inches on drainage area	Run-off	
	Maximum	Minimum	Mean	Mean per sq. mi.		Depth in inches on drainage area	Total in acre-feet
1917							
January	1,982	180	427	0.237	2.33	0.271	26,000
February	196	154	161	0.089	0.40	0.092	8,900
March	1,084	143	307	0.171	2.14	0.196	18,800
April	3,152	227	593	0.329	5.22	0.367	35,200
May	8,134	289	1,115	0.619	3.95	0.713	68,500
June	3,528	165	1,030	0.572	2.87	0.635	61,000
July	2,128	143	302	0.168	3.84	0.193	18,500
August	826	154	327	0.182	5.69	0.209	20,100
September	3,152	122	404	0.224	3.38	0.250	24,000
October	149	122	131	0.073	1.00	0.083	8,000
November	149	111	129	0.072	2.22	0.079	7,600
December	690	154	284	0.158	1.02	0.181	17,400
The Year	3,528	111	434	0.241	34.06	3.269	314,000
1918							
January	352	143	183	0.102	1.49	0.116	11,200
February	1,380	289	686	0.382	0.75	0.396	38,000
March	438	211	297	0.165	1.48	0.189	18,200
April	17,080	196	3,212	1.782	6.66	1,961	190,500
May	21,450	419	2,880	1.600	4.55	1.840	176,500
June	988	133	343	0.191	4.78	0.227	21,800
July	495	122	257	0.143	2.24	0.165	15,800
August	457	133	176	0.098	4.12	0.111	10,700
September	384	143	202	0.112	3.23	0.125	12,000
October	227	111	150	0.083	1.86	0.096	9,200
November	1,180	143	400	0.222	2.73	0.248	23,800
December	8,514	320	1,465	0.845	3.73	0.935	89,900
The Year	21,450	111	854	0.477	37.62	6.409	617,600

MONTHLY DISCHARGE OF GASCONADE RIVER AT CROCKER-WAYNESVILLE BRIDGE, 1914-1920—Continued.

Month	Discharge in second-feet				Rainfall in inches on drainage area	Run-off	
	Maximum	Minimum	Mean	Mean per sq. mi.		Depth in inches on drainage area	Total in acre-feet
1919							
January	1,598	258	618	0.343	0.52	0.394	37,900
February	4,104	227	838	0.465	2.05	0.485	46,500
March	2,284	419	867	0.481	1.81	0.554	53,200
April	826	289	385	0.214	2.23	0.237	22,800
May	15,750	826	3,840	2.134	6.90	2.460	236,000
June	14,990	537	2,710	1.505	5.82	1.676	161,000
July	1,280	165	393	0.218	2.93	0.250	24,000
August	457	143	241	0.134	3.43	0.154	14,800
September	457	154	200	0.111	2.22	0.123	11,800
October	22,210	143	2,800	1.555	10.79	1.790	172,000
November	20,120	495	3,920	2.179	3.78	2.500	240,000
December	4,700	570	1,440	0.800	0.99	0.814	78,200
The Year	22,210	143	1,520	0.843	43.47	11.437	1098,200
1920							
January	6,220	258	1,346	0.747	2.26	0.860	82,600
February	2,284	419	936	0.520	0.72	0.559	53,700
March	14,990	289	3,208	1.782	6.43	2.053	197,107
April	2,700	650	1,362	0.757	2.00	0.845	81,000
May	6,700	650	2,270	1.260	5.68	1.450	139,200
June	13,600	280	2,203	1.220	1.55	1.367	131,000
July	4,800	210	919	0.510	3.40	0.618	59,300
August	1,200	210	497	0.276	5.97	0.318	30,500
September	20,700	580	2,026	1.125	6.98	1.256	120,400
October	4,500	370	1,002	0.556	4.56	0.640	61,400
November	1,380	330	569	0.316	0.54	0.352	33,800
December	1,200	280	673	0.374	2.11	0.432	41,400
The Year	20,700	210	1,430	0.790	42.20	10.750	1031,400

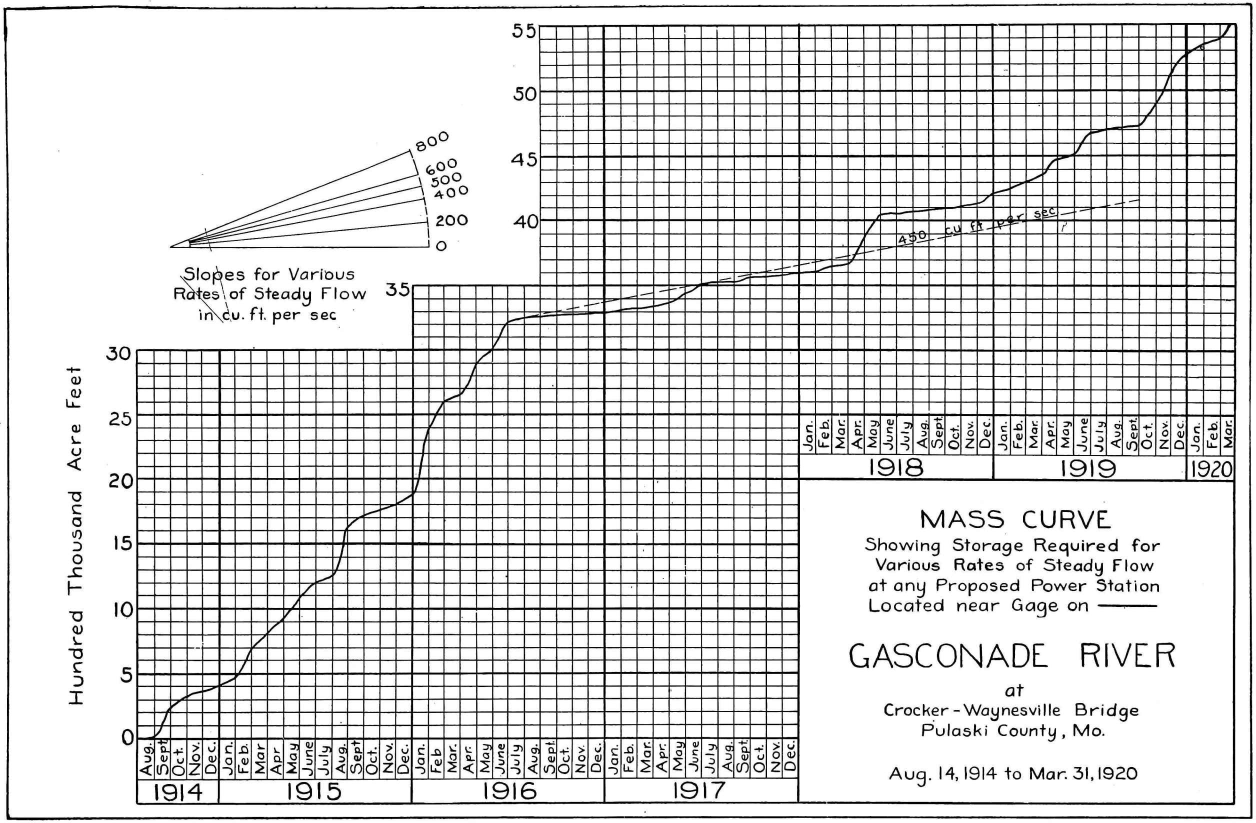
*Estimated.

PLATE XV.



Rainfall Chart Gasconade Watershed

PLATE XVI.

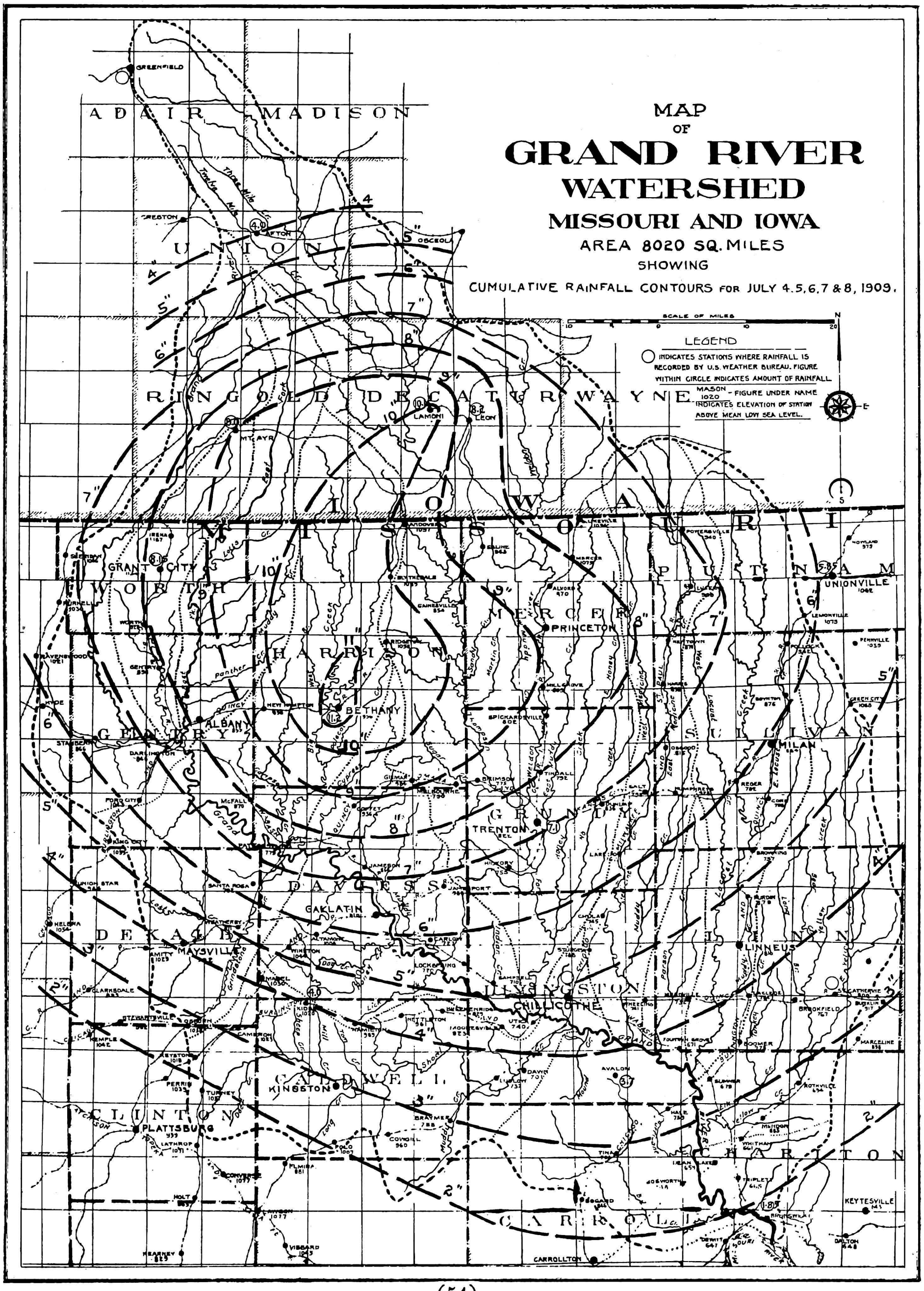

Slopes for Various Rates of Steady Flow in cu. ft. per sec
800
600
500
400
200
0
450 cu. ft. per sec
Hundred Thousand Acre Feet
0
5
10
15
20
25
30
35
40
45
50
55
Aug. Sept. Oct. Nov. Dec.
1914
Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec.
1915
Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec.
1916
Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec.
1917
Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec.
1918
Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec.
1919
Jan. Feb. Mar.
1920
MASS CURVE
Showing Storage Required for
Various Rates of Steady Flow
at any Proposed Power Station
Located near Gage on ———
GASCONADE RIVER
at
Crocker - Waynesville Bridge
Pulaski County, Mo.
Aug. 14, 1914 to Mar. 31, 1920

The Mass Curve.—The mass curve for the Gasconade River showing the accumulated discharge is presented on page 52. From July, 1916, to April, 1918, twenty-one months, the mass curve shows a low rate of flow of the river. This low rate of flow corresponds to the relatively low rainfall over the same period as presented in the rainfall chart for this watershed (Page 51). The rainfall as given in the chart is the mean of the records taken from three U. S. Weather Bureau Stations on the upper watershed.

Water Power and Storage.—An examination of the mass curve (Page 52) indicates that large storage capacity will be required on the Gasconade River if any considerable amount of continuous power is to be developed at a single power station. The river valley is generally wide, ranging from 1,000 to 4,000 feet. It possesses considerable storage capacity for any proposed height of dam. Surveys of the most favorable storage basins and power sites are needed to determine the available power which this stream is capable of supplying.

THE BLACK RIVER WATERSHED

In the upper portion of the watershed of Black River the surface topography is somewhat similar to that of Current River. The general fall of the main river, however, is less per mile than the fall of Current River, and its trough or valley is generally somewhat wider. Measurements of the water flow in August, 1913, indicate that the low-water discharge per square mile of drainage area is approximately 0.30 cubic feet per second, a little less than that of the Current River Basin. A satisfactory gaging station has not yet been established on this river. The general form and the extent of the Black River watershed is presented on the map, pages 30 and 31.


MAP
OF
GRAND RIVER
WATERSHED
MISSOURI AND IOWA
AREA 8020 SQ. MILES
SHOWING
CUMULATIVE RAINFALL CONTOURS FOR JULY 4, 5, 6, 7 & 8, 1909.
SCALE OF MILES
LEGEND
INDICATES STATIONS WHERE RAINFALL IS RECORDED BY U.S. WEATHER BUREAU. FIGURE WITHIN CIRCLE INDICATES AMOUNT OF RAINFALL.
MASON 1020 - FIGURE UNDER NAME INDICATES ELEVATION OF STATION ABOVE MEAN LOW SEA LEVEL.
IOWA
MISSOURI
ADAIR
MADISON
UNION
RINGGOLD
DECATUR
WAYNE
PUTNAM
WORTH
HARRISON
MERCER
GENTRY
SULLIVAN
GRUNDY
DAVIESS
DEKALB
LINN
LIVINGSTON
CALDWELL
CLINTON
CHARITON
CARROLL
GREENFIELD
CRESTON
AFTON
OSCEOLA
LAMONI
LEON
MT. AYR
GRANT CITY
PRINCETON
BETHANY
ALBANY
MILAN
TRENTON
GALLATIN
MAYSVILLE
LINNEUS
CHILLICOTHE
KINGSTON
PLATTSBURG
UNIONVILLE
BROOKFIELD
KEYTESVILLE
CARROLLTON

FLOOD-PRODUCING STORMS AND FLOOD PROTECTION

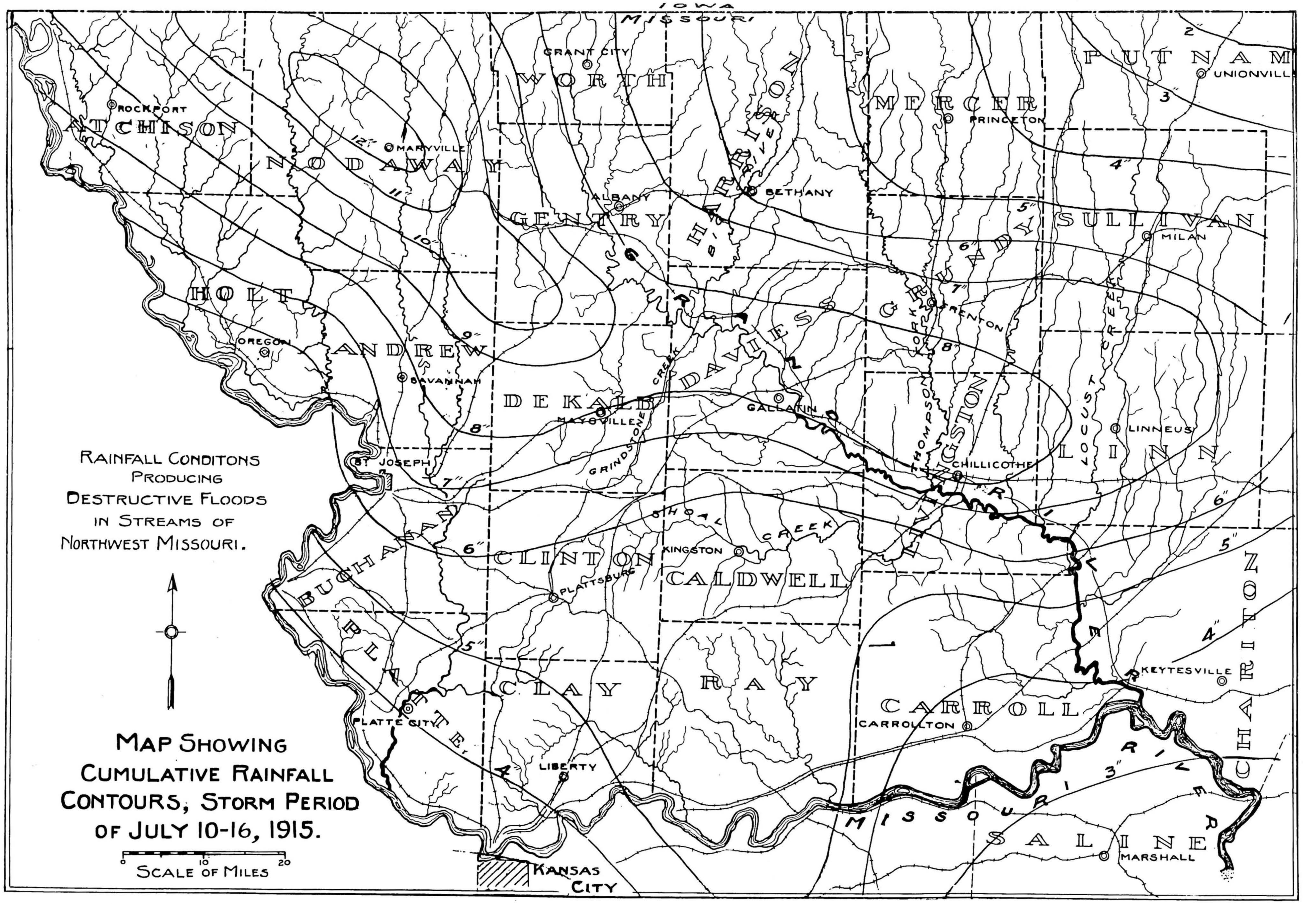
The value of reliable information regarding conditions which seriously affect the flow of our rivers has been mentioned in the introduction to this bulletin. Persons interested in problems of water power development are mostly concerned with the low-water flow of streams, while those interested in the problems of drainage and reclamation of low lands are more concerned with high-water flow of the rivers and the conditions which produce excessive floods.

In 1908, 1909, 1915, and 1917 severe flood-producing storms occurred in Missouri, especially in the central and northwestern portions of the state. The floods produced were very disastrous to farming interests, and particularly to the lands lying in the river valleys where protective measures such as ditches and levees had not been provided. Two charts showing the accumulated rainfall which produced the floods of 1909 and 1915 are presented on pages 52 and 54. These charts show conditions in rainfall concentration over considerable areas that are quite typical of the conditions which produce excessive floods in this region. Four of these unusual storm periods occurred within 10 years, 1908 to 1917 inclusive. That they may be expected so frequently in the future cannot be predicted. But that similar storm periods may occur so frequently as to make it imperative and worth while to provide more extensive and complete protection against overflow of the rivers is quite certain. That they will occur at least once in from five to seven years is very probable. The economic features involved in the problems of drainage improvements and flood protection include the frequency, seasonal time, and magnitude of the floods. All of the floods mentioned above occurred in the summer and in the midst of the crop-growing and crop maturing season, so that the loss included not only the crops destroyed but also the use of the land for practically the entire year.

*Plate XVIII, page 54, shows the accumulated rainfall over the Grand River valley of the storm period occurring July 4 to 8, 1909. It will be noticed that Bethany, in Harrison County, was the center of the greatest amount of rainfall, a total of 11.2 inches in five days. On the third day of the storm period a total of 7.91 inches fell in one day. The contours of accumulated rainfall spread out from Bethany as a center, gradually diminishing in total rainfall represented, but nowhere in the main watershed falling below 3 inches.

Plate XIX, page 56, shows the accumulated rainfall over practically all of the watersheds in the northwestern portion of Missouri during a storm period from July 10 to 16, 1915. Maryville, in Nodaway County,

*Courtesy of Jacoby Engineering Co., Kansas City, Mo.



MAP SHOWING CUMULATIVE RAINFALL CONTOURS, STORM PERIOD OF JULY 10-16, 1915.

was the center of the greatest rainfall, a total of 12 inches in seven days. The maximum intensity of rainfall at this place was 6.77 inches on July 14, the fifth day of the storm period. All of the streams in Northwest Missouri went out of their banks, and the crops in the lowlands were practically all destroyed.

Protection against the overflow of streams produced by conditions presented in these two charts becomes a difficult and expensive undertaking. Such problems will require careful study and analysis of the high water levels, the amount of flow in the flood plains of the rivers, and consideration of possible storage or holding basins sufficient in capacity to keep down the crest of the advancing high water. *Gage readings of the 1909 flood observed on the Grand River show that this stream rose some 29 feet above the ordinary low-water stage of the river at Chillicothe, Mo. The maximum estimated flow from measurements* taken with current meters thru bridge openings on the Santa Fe Railway crossing during a similar flood whose crest height was about 3 feet less than in 1909 indicate a maximum discharge of approximately 183,000 cubic feet per second for 1909, or 24 cubic feet per second per square mile from the Grand River watershed, which has an area of about 8,000 square miles. The results of these observations are valuable in that they confirm formulas used in engineering practice for estimating unusual flood discharge of rivers. Further study and observation on streams of Missouri are needed in order that the flood conditions may be more fully understood and better provision made for protection against these serious overflows.

*Data on stages of Grand River were furnished by Jacoby Engineering Co., Kansas City, Mo.

UNIVERSITY OF MISSOURI BULLETIN

ENGINEERING EXPERIMENT STATION SERIES

EDITED BY

E. J. McCAUSTLAND

Dean of the Faculty of Engineering, Director of the Engineering Experiment Station

Some Experiments in the Storage of Coal, by E. A. Fessenden and J. R. Wharton. (Published in 1908, previous to the establishment of the Experiment Station.)

Vol. 1, No. 1.—Acetylene for Lighting Country Homes, by J. D. Bowles, March, 1910.

Vol. 1, No. 2.—Water Supply for Country Homes, by K. A. McVey, June, 1910.

Vol. 1, No. 3.—Sanitation and Sewage Disposal for Country Homes, by W. C. Davidson, September, 1910.

Vol. 2, No. 1.—Heating Value and Proximate Analyses of Missouri Coals, by C. W. Marx and Paul Schweitzer. (Reprint of report published previous to establishment of Experiment Station.) March, 1911.

Vol. 2, No. 2.—Friction and Lubrication Testing Apparatus, by Alan E. Flowers, June, 1911.

Vol. 2, No. 3.—An Investigation of the Road Making Properties of Missouri Stone and Gravel, by W. S. Williams and R. Warren Roberts.

Vol. 3, No. 1.—The Use of Metal Conductors to Protect Buildings from Lightning, by E. W. Kellogg.

Vol. 3, No. 2.—Firing Tests of Missouri Coal, by H. N. Sharp.

Vol. 3, No. 3.—A Report of Steam Boiler Trials under Operating Conditions, by A. L. Westcott.

Vol. 4, No. 1.—Economics of Rural Distribution of Electric Power, by L. E. Hildebrand.

Vol. 4, No. 2.—Comparative Tests of Cylinder Oils, by M. P. Weinbach.

Vol. 4, No. 3.—Artesian Waters in Missouri, by A. W. McCoy.

Vol. 4, No. 4.—Friction Tests of Lubricating Oils and Greases, by A. L. Westcott.

No. 14.—Effects of Heat on Missouri Granites, by W. A. Tarr and L. M. Neuman.

No. 15.—A Preliminary Study Relating to the Water Resources of Missouri, by T. J. Rodhouse.

No. 16.—The Economics of Electric Cooking, by P. W. Gumaer.

No. 17.—Earth Roads and the Oiling of Roads, by H. A. LaRue.

No. 18.—Heat Transmission Thru Boiler Tubes, by E. A. Fessenden and J. W. Haney.

No. 19.—Geology of Missouri, by E. .B Branson.

No. 20.—Energy Necessary to Shear Steel at High Temperatures, by Guy D. Newton.

No. 21.—Water Supply and Sewage Disposal for Country Homes, by E. J. McCaustland.