A PRELIMINARY STUDY RELATING TO THE WATER RESOURCES OF MISSOURI

BY

T. J. Rodhouse
Associate Professor of Hydraulic Engineering

UNIVERSITY OF MISSOURI
COLUMBIA, MISSOURI
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Where the Niangua and Osage Rivers Meet. Typical Topography of the Ozark Streams. [Photo by J. K. Wright]
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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 a period of 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 through 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 of time. 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 nor 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 can not 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 throughout 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 to 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 overflows, 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 preliminary report.—A comprehensive study of the apparent erratic action of streams reveals the fact that there are natural laws, not always clearly defined, which control their action. 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. How-
ever, 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 ap-
proximately 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 located outside the
watershed and distant 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 the
year 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.)

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

* 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 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 such springs are to be found. Careful measurements of the discharge of a number of these noted springs were made

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*The origin and geology of these springs is reported in Water Supply Papers, Nos. 110 and 145, U. S. Geological Survey.
Fig. 1. Bennett's Spring, on the Niangua River

Fig. 2. Alley Spring, on Jack's Fork of Current River
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 Spring.—Three large springs were observed on the Niangua River. The largest of these is Bennett's Spring, located 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 a distance of one and a half miles where it empties 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 located nearby. The measured flow of the spring, on June 28, 1913, was 98.44 cubic feet per second, equivalent to 63,500,000 gallons per day.

Figure 1, Plate II., is from a photograph of this spring.

Big Blue Spring.—This spring is located 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. The location of this spring is in Camden County, and is 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 through a narrow rugged canyon for a distance of nearly 1000 feet where it 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 (Plate III) 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.
Plate IV.

Fig. 1. Big Spring, on Current River

Fig. 2. Gaging Station on Current River
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 located 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 twelve-foot falls, there driving the water turbine of a mill. From this point it flows in a swift course a distance of a half mile where it joins the waters of Jack’s Fork. This spring (See Fig. 2, Plate II) 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 by far the largest of any of the springs observed in these investigations up to the present time. It is located 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, Plate IV.) The water flows rapidly in a channel about 100 feet wide which runs due east a distance of 1000 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 located 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.
WATERSHEDS OF THE
Black River
Area 1735 Sq. Miles
AND THE
St Francis River
Area 2335 Sq. Miles
Scale 1=6 Miles
Creasey Spring.—This spring is the second one of this group and is located 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 other three springs of this group are located about 200 yards above Creasey Spring. Two of them issue from gravel beds in the river channel and the third is located 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.

Keener Spring.—This spring is located 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.

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 1800 feet, at Taum Sauk, in Iron County. At Cedar Gap, in Wright County, the elevation is 1700 feet. Between these points the elevation along the divide is from 1200 to 1600 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.

*A full description of the geology of this region will be found in Water Supply Paper No. 114, U. S. Geological Survey.
Characteristic Topography Along Current River
Plate VI.

View Along Current River
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 1200 to 1500 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 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 through 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 ninety 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 1000 to 3000 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, Plate IV) 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
Plate VIII

Watershed of the Current River
Area 1812 Sq.Mi.
Above Van Buren
Scale 1 in. = 6 mi.
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. The records are
reliable and accurate for all ordinary and low-water stages of the river.

The daily discharge of the river is indicated on the hydrograph of
Plate VII.

The monthly discharge from September, 1912, to November, 1914,
is presented in the table which follows on page 27.

RAINFALL ON CURRENT RIVER WATERSHED

Mean Annual Rainfall.—The mean annual rainfall for a period of
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 located within the
Current River watershed. Two of the other stations are located 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 twenty years, 1894 to 1913, 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 satisfac-
torily the effect of unusual dry weather on the rate of run-off.

The variations in the monthly and annual rainfall for this region,
over a period of twenty years, are graphically represented in the chart,
Plate IX. The fluctuations in the seasonal distribution are clearly
apparent.

The amount of the monthly and annual rainfall, covering the period
of time in which observations on run-off on Current River were made,
has been tabulated for the purpose of comparative study, and appears
in the table on page 27 of this report.
Monthly Rainfall, Current River Watershed
### Monthly Discharge of Current River at Van Buren, Missouri, from August 25, 1912, to November 30, 1914

(Drainage area, 1812 square miles)

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<th>Run-off in inches on drainage area</th>
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*Estimated.
FLOW OF CURRENT RIVER

Maximum Flow.—Referring to the table of monthly discharge of Current River (page 27) it will be seen that the maximum flow during the period in which observations have been made was about 36,000 cubic feet per second in April, 1914, at the Van Buren gaging station. This is equivalent to twenty 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:

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<td>May 1</td>
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Total rainfall 5.68 inches.

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. Former high-water marks indicate that the maximum discharge of Current River has greatly exceeded the highest rate observed since establishing the gage. The writer believes that over thirty cubic feet per second per square mile may occasionally be expected from this watershed.

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 flow for the year 1913 was 1151 cubic feet per second, or 0.635 cubic feet per second, per square mile of drainage area. In 1914 the mean was 1335 cubic feet per second, or 0.738 cubic feet per second per square mile.

A mean annual flow of not less than 1000 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

*U. S. Weather Bureau records.
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 extended 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 1135 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 0.403 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 fluctuations 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 required 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 Plate X. Its construction consists in adding up the daily discharge of the stream, from month to month, for the whole series of discharge observations, 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.
Slopes for Various Rates of Steady Flow in cu.ft. sec.

Mass Curve Showing Storage Required for Various Rates of Steady Flow

Current River
Van Buren, Mo.
Aug. 25, 1912 to Nov. 30, 1914.
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 1000 cubic feet per second. The storage required for maintaining this steady draft on a twenty-four-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 1000 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 twenty-five feet the power available at this point on the river would amount to about 2500 horse power for a continuous twenty-four hour service. Estimated on the basis of service of sixteen hours per day and a fifty per cent load factor the nominal capacity of the plant would be raised to approximately 7500 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 1000 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.
Plate XI

Watershed of the Niangua River
Area 1045 Sq. Mi.

Scale 1" = 6 Miles
THE NIANGUA RIVER WATERSHED

The Niangua River watershed lies on the north slope of the Ozark Plateau. Though 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 Plate XI.

The width of the Niangua valley is approximately 1000 to 2500 feet. The hills rise precipitously 150 to 400 feet in height on either side of the valley. Favorable sites for storage are located 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.

THE GASCONADE RIVER WATERSHED

A preliminary examination was made of a portion of the Gasconade watershed, and a gage was established at the highway bridge located on the road between Crocker and Waynesville, Pulaski County. The gage was established on August 15, 1914. Gage readings are observed daily, and several measurements of the flow at low and ordinary 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. It is proposed to continue these observations over a sufficient time to obtain more complete and reliable results. A map of this drainage basin is presented in Plate XII. The general character of the topography of this watershed, and the indications from the very limited discharge measurements already taken give promise of interesting power possibilities on this river.

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, Plate XIV, pages 18-19. A view of the river at low-water stage having a discharge of 287 cubic feet per second is shown in Fig. 2, Plate XIII. The yield at this stage of the river is 0.24 cubic feet per second per square mile.

Plate XIII

Fig. 1. Gasconade River

Fig. 2. Black River at Leeper
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BULLETIN

VOLUME 15
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E. J. McCaustland

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

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