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FLOW OF WATER IN DRAINAGE CHANNELS
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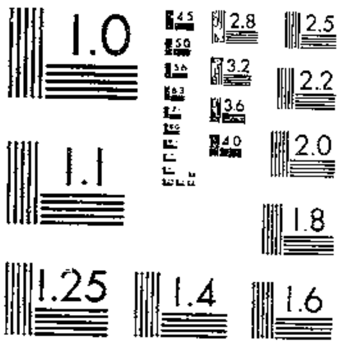

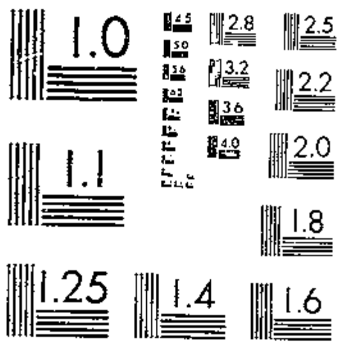

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TECHNICAL BULLETIN No. 129 — November, 1929

UNITED STATES DEPARTMENT OF AGRICULTURE
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FLOW OF WATER IN DRAINAGE CHANNELS[1]

THE RESULTS OF EXPERIMENTS TO DETERMINE THE ROUGHNESS COEFFICIENT *n* IN KUTTER'S FORMULA

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INTRODUCTION

Kutter's formula is generally accepted by engineers as being the most satisfactory formula in use for computing the flow of water in open channels. After a thorough and unbiased study of all known formulas for computing the flow in open channels, engineers of the Miami conservancy district concluded that "although the Kutter formula is not ideal it is the best equation available at the present time."[2] The results obtained by the use of this formula are, however, affected to such a degree by the coefficient of roughness, *n*, that the selection of the correct value for this factor is a matter of the highest importance. The series of experiments described and summarized in the following pages were made for the purpose of determining just what values of *n* properly apply to the various conditions of channel, and the endeavor has been made to present this information in the form that will be of the most practical value to engineers charged with the design of drainage channels or the computation of the discharge capacity of existing channels.

[1] This bulletin is a revision of and supersedes Department Bulletin 832, The Flow of Water in Dredged Drainage Ditches.

[2] HOUK, I. E. CALCULATION OF FLOW IN OPEN CHANNELS. Miami [Ohio] Conserv. Dist., Tech. Rpts. pt. 4, 283 p., illus. 1918.

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The term n in Kutter's formula is a measure of all the conditions in a channel that tend to retard the flow. It is quite often regarded as simply a measure of the friction between the flowing water and the material forming the perimeter, all other conditions in the channel being disregarded. Some of the conditions that influence the value of n for earth channels are irregularities in the wetted perimeter, nonuniformity of cross section in size and shape, the growth of vegetation in the channel, such as grass, weeds, roots, vines, bushes and trees, and the presence of other obstructions to flow, such as logs, stumps, drift, and débris of all kinds. Various combinations of these conditions that may exist in a channel make it difficult to choose the proper value of n in computing the flow of an open channel or the probable flow for proposed artificial channels. The engineer who has had a wide personal observation of conditions in channels for which values of n have been determined is generally well qualified to choose the proper values of n in the design of channels. On the other hand, the engineer who has not had similar experience must depend for his choice of n upon views and descriptions of channels for which values of n have been determined by experiment. In this bulletin, views and careful descriptions of the channels for which values of n were determined are presented as being the best method of making the results of practical application.

The experiments described were conducted in nine different localities, namely, Lee County, Miss.; Washington and Bolivar Counties, Miss.; western Tennessee; western Iowa; southern North Carolina; eastern Florida; eastern Arkansas; southeastern Missouri; and central Illinois. All of the experiments with the exception of those in North Carolina and Florida were made by the author, or under his immediate direction by other engineers of the United States Department of Agriculture. The experiments in North Carolina were made by A. D. Morehouse, and those in Florida by F. E. Staebner and A. O. Kay, also engineers of this department. The field data in Arkansas were collected by P. T. Simons, those in Illinois by R. A. Norton, and those for the second set of experiments in Washington and Bolivar Counties, Miss., by B. S. Clayton; in Tennessee, H. S. Andrews and A. L. Lane assisted in collecting the data. The experiments in central Illinois were made in cooperation with the engineering experiment station of the University of Illinois, represented by G. W. Pickels. All of the experiments were conducted under the general direction of S. H. McCrory, Chief of the Division of Agricultural Engineering.

FIELD MEASUREMENTS

DISCHARGE

Particular care was taken to secure accurate discharge measurements. With few exceptions the gaging stations were located on single span bridges, so that there was no interference with the natural flow of the water. Where suitable existing bridges at desirable sections could not be found, suspension footbridges were constructed, one of which is shown in Plate 17, C. A cable gaging station was built on the Bogue Phalia Channel in Bolivar County, Miss. Where the cable stations and suspension bridges were built, ideal gaging sections were obtained.

Velocity measurements were made with a small Price current meter. These measurements were made at intervals of 2½ feet across the streams for the smallest channels, 5 feet for the medium-sized channels, and 10 feet for the largest channels, except as noted for the flood ways in Arkansas and Missouri. At the measuring points the velocity was determined at the surface, mid-depth, and the bottom of the stream. In a few instances the velocity was measured at 0.2 and 0.8 depths. The best methods were observed in the use and care of the current meter, and it is believed that the results are entirely dependable.

Carefully made soundings were obtained during low-water stages at the velocity-measuring points and wherever a decided change in the perimeter of the channel took place. As a check on these measurements, and to detect any changes due to silting or erosion, soundings were also made at the time of the velocity measurements. The depths were measured to the nearest tenth of a foot.

SLOPE OF WATER SURFACE

The slope of the water surface, except in a few cases, was measured along the straightest and most uniform course of channel available near the gaging station. The courses chosen were such that no tributary streams entered the channel and no decidedly abrupt changes in the bottom grade of the channel occurred along the courses, and ordinarily were so located as to exclude such obstructions as logs, fallen trees, piling, and bridge piers. In one experiment, however, courses were chosen with a view to determining the influence of such obstructions upon the flow. Where not limited by the conditions named above, the length of the course was made at least ten times the top width of the channel. It was apparent that representative values of n could not be obtained for a channel if a long course were chosen without regard to the conditions mentioned above. For instance, during a high stage in the Bogue Hasty channel, in Bolivar County, Miss., drift accumulated at a pile trestle bridge just above the slope course, causing a fall of 0.3 foot from the upstream to the downstream side of the bridge. The actual slope of the water surface for this channel was less than 1 foot per mile, from which it is apparent that had a long slope course been chosen which included this bridge, decidedly different values of n would have been obtained. Also where long slope courses are used, incorrect values of n are often obtained, due to the entrance of surface water along the course.

In these experiments the slope of the water surface was determined by making vertical measurements from permanently set reference points to the surface of the water. These reference points were established on horizontal arms extending from vertical posts set firmly in the ground at each end of the course. Variations in water level of from 3 to 4 feet could be measured from each post, and a sufficient number of posts were set on the side slope of the channel so that all fluctuations in water surface could be measured. The elevations of the points on the arms of the posts were determined with a level to the nearest two or three thousandths of a foot and were carefully checked after every high stage in the stream to detect any possible changes due to the disturbance of the posts. The posts, however, were set in such a substantial manner, that very seldom were any changes found. The vertical measurements from the points on the arms to the water surface were made with a hook-gage measuring rod. In some instances a stilling box arrangement was employed in connection with the hook gage. These measurements were made either before or after the gaging was made, and often both before and after. They were made simultaneously by observers at either end of the course, or by one observer who first read at the end of the course nearer the gaging station, then at the other end, and then repeated the first measurement, the average of the first and third measurements being used. This method is based upon the assumption that the same time elapses between the first and second measurements as between the second and third measurements; hence errors due to a rising or falling stage are practically eliminated. Realizing that the accuracy of the results depended largely upon a correct determination of the slope, the utmost care was taken to secure accurate and dependable slope measurements.

CROSS SECTIONS

The length of the slope course was carefully measured along one bank of the stream and stakes were placed at intervals of 50 or 100 feet to mark the points where the cross sections were to be taken. Where the channel was regular the cross sections were taken at intervals of 100 feet. Where the channel was irregular they were taken 50 feet apart, or at such irregular intervals as to represent as nearly as possible the true average cross section of the course. In making the cross-sectional measurements, distances across the channel were measured from the stakes to the nearest tenth of a foot. For the smaller channels, where wading was possible, elevations on the bottom and side slopes of the channels were taken with a level and rod to the nearest tenth of a foot, and were taken at intervals of 5 feet across the channel and at all points where a change in slope occurred. For the larger channels the measurements in the water section were generally taken from a boat attached to a rope stretched across the stream and fastened securely on both sides.

COMPUTATIONS

In the experimental determination of the value of n in Kutter's formula.

$$C=\frac{41.6+\frac{1.811}{n}+\frac{0.00281}{S}}{1+\left(41.6+\frac{0.00281}{S}\right)\frac{n}{\sqrt{R}}}$$

the coefficient C is first obtained from Chezy's formula,

$$V=C\sqrt{RS}$$

and then the value of n by solving for n in Kutter's formula. In solving Chezy's formula for C the following terms must be known:

V, the mean velocity along the slope course.

R, the mean hydraulic radius along the slope course.

S, the mean slope of the water surface along the slope course.

As has been explained, the data required for computing these values were obtained by field measurements. The mean velocity,

V, was determined by dividing the discharge by the mean cross-sectional area of the channel along the slope course. The discharge was computed from the soundings and velocity measurements made at the gaging section. The method of computing the discharge was as follows: The mean velocity in the vertical at each velocity measuring point was obtained by taking one-sixth of the sum of the velocity at the surface, four times the velocity at mid-depth, and the velocity at the bottom, or by taking the mean of the velocities obtained at 0.2 and 0.8 depths. The mean velocity for each section between the verticals was taken as the average of the mean velocities for the verticals on either side of the section, and the discharge for each section was obtained by multiplying the mean velocity for the section by the area of the section. The total discharge of the stream was obtained by taking the sum of the discharges for all sections across the stream.

The cross-sectional measurements were platted on cross-section paper, on a scale of 5 or 10 feet to the inch, depending upon the size of the channel. The areas and wetted perimeters for each cross section were obtained by means of a planimeter and map measurer. The mean cross-sectional area, which was used in determining the mean velocity for the course, was obtained by taking the average of all the cross-sectional areas along the course.

For some of the channels the mean hydraulic radius for the course was obtained by taking the average of all the hydraulic radii as computed for each cross section; for others it was obtained by dividing the mean cross-sectional area by the average of all the wetted perimeters as determined for each cross section along the course. There was no appreciable difference in the results obtained by the use of the two methods unless the channel was subject to large variations in cross section, in which case the first method was used.

On all of the channels the slope of the water surface was practically uniform from the upper to the lower ends of the slope courses, and the differences in the velocities at the upper and lower ends of the courses were generally so small that the application of a correction for the difference in velocity heads was found to be unnecessary, so far as the practical value of the results was concerned. In a few instances, where a rather gradual change in the size of the cross section occurred along the slope course, a correction for a difference in velocity heads might have been justified.

In calculating values of n, the values of V, R, and S were first determined as explained in the foregoing, and C was then computed by Chezy's formula. With C, R, and S known, the values of n in the first six sets of experiments were obtained from a large-scale diagram similar to, but larger than, the one found in Hering and Trautwine's translation of Ganguillet and Kutter's treatise, A General Formula for the Uniform Flow of Water in Rivers and Other Channels.[3] The value of n in the other three sets of experiments were computed by Kutter's formula.

[3] GANGUILLET, E., and KUTTER, W. R. A GENERAL FORMULA FOR THE UNIFORM FLOW OF WATER IN RIVERS AND OTHER CHANNELS. Translated from the German by R. Hering and J. C. Trautwine, Jr. Ed. 2, 240 p. illus. New York. 1893.

TABULATED RESULTS

In Tables 1 to 9 are given the hydraulic elements and values of C and n for the nine sets of experiments. In the third column is shown the average of the maximum depths as measured at each of the cross sections. At the foot of this column is shown the average maximum depth for a bankful stage of each channel, which enables the reader to estimate about what proportion of the channel is filled for each measurement. In the fourth column is given the average surface width along the slope course at the time of each measurement. With these two dimensions, the average cross-sectional area given in column 6, and the accompanying cross-sectional figures for each channel, a good idea can be obtained as to the shape and size of the channel. The headings at the tops of the other columns in the tables are self-explanatory. On most of the channels values of n were determined for several stages ranging from low to high.

Attention is called to the specially interesting features of some of the experiments. For instance, values of n for Old Town Creek, Table 1, were obtained before and after clearing, in order to show the effect upon n as produced by the presence of growth in the channel.

On the South Forked Deer River at Campbell's levee, near Jackson, Tenn., experiments were conducted to determine the relative values of n for three consecutive courses of channel; the first, an old straight course of the river channel; the second, an old crooked course of the river channel; and the third, a course of an irregularly dredged channel. The results, which are given in Table 3, show a remarkable difference in the values of n obtained for the three different conditions of channel.

In the results of the Iowa experiments (Table 4) attention is called to the unusually low values of n obtained for earth channels. These low values, which were obtained for Boyer River and Allen and Willow Creeks, were due, no doubt, to the smoothing up of irregularities by silting and to the lubricating effect of silty mud deposited on the bottom and side slopes of the channels. The increase in the value of n, due to a caving bank covered with a heavy growth, is shown by the experiments made on the Little Sioux River cut-off channel before and after the caving took place.

The increase in the value of n, due to the growth of grass in channels, is shown by the results of the experiments made in North Carolina. (Table 5.) These experiments were made during the winter and the following summer, before and after the growth of grass in the channels.

The experiments on the flow of water in the main diversion flood way of the Little River drainage district in Missouri are among the first of their kind ever attempted. Measurements were obtained on both a cleared course and an uncleared course, and afford data of value on the relative capacities of such waterways under the conditions represented. (Table 8.) The measurements in St. Francis River flood way in Arkansas show much higher values of n for flow through virgin timber with little undergrowth. (Table 7.)

The experiments in Arkansas and Illinois on a large number of ditches with a wide variety of conditions of vegetation demonstrate the need for systematic maintenance of drainage ditches. In these two sets of experiments measurements were made on the same ditches both before and after clearing and before and after the appearance of growth in the ditches. (Tables 7 and 9.)

Values of n were obtained for two large natural river channels, the Bogue Phalia, in Mississippi and the Embarrass River, in Illinois. (Tables 2 and 9.)

DESCRIPTION OF CHANNELS

At the right-hand side of each of the Tables 1 to 9 is given a complete description of each drainage channel. These detailed descriptions, supplemented by the views of the channels shown in the plates, are intended to assist the engineer in the proper choice of n for his particular use. Under the descriptions of channels are included the factors or conditions that influence the flow of water in a channel. These factors are described under the following headings: Course, cross section, side slopes, bottom, soil, and condition. Also the approximate date when the channel was constructed is given, from which can be determined the age of the channel at the time the experiments were made.

COURSE

The length and alignment of the course of channel are discussed under this heading. Where the length of the course is unduly short, the probability of error in the slope measurements is somewhat greater than where it is comparatively long. It was impossible in many instances, other governing factors being duly considered, to follow the general rule adopted, namely, that the length of the slope course should be at least ten times the top width of the channel. With the exception of two courses of channels, the alignment of the slope courses was practically straight. These exceptions consisted of a bend in the Sugar Creek channel and of several irregular crooks in the old river channel at Campbell's levee, near Jackson, Tenn. (Table 3.)

CROSS SECTION

Under this heading variations in the shape of the cross section along the courses are noted, and the reader is referred to figures which show the per cent variation from the average cross-sectional area for all cross sections along each slope course. In most cases this per cent variation is shown for low, medium, and high stages. From these figures an idea can be obtained as to the progressive changes in size of the channel along the courses and whether these changes are gradual or abrupt. For instance, in Figure 2, A it is seen that the per cent variations are much larger and the changes in size of the channel along the course are much more abrupt for the low than for the high stage, which accounts largely for the higher values of n obtained for the low stages as recorded in Table 1.

It was found that abrupt changes in the size of a channel that are repeated at short intervals are often alone responsible for the high values of n obtained.

The average cross sections for all of the channels are shown, and the description of each channel makes reference to the corresponding illustration. From these a general idea can be obtained as to the size and shape of the various channels.

SIDE SLOPES AND BOTTOM

Irregularities in the perimeter of the channel are discussed under the two headings, side slopes and bottom, for the reason that the bottom alone is often the chief retarding factor during low stages.

Irregularities in the perimeters of channels have a very decided effect upon the value of n. For instance, irregularities in the side slopes of the South Forked Deer River near Jackson, Tenn., were largely responsible for the higher values of n obtained for this course than were obtained for the same channel near Roberts, Tenn., where the side slopes were much more regular. (Table 3.) The irregularities in the channel at Jackson were due to rough finishing work with the dredge at the time of construction. To smoothness of perimeter may be attributed in part the low values of n obtained for the Allen and Willow Creek channels in western Iowa. (Table 4.)

SOIL

Under this heading descriptions of the different types of soils found in the various channels are given. However, no noticeable difference in the retarding effect of the different soils was detected. All of the soils are of an alluvial nature, except in central Illinois, the lands through which the ditches were dug having been built up by deposits of silt brought down from the hills during heavy rains. In Illinois the ditches lie in the extreme uppermost parts of comparatively flat watersheds, and the soil is chiefly a black or mixed clay loam of glacial origin.

CONDITION

An effort has been made to describe accurately the condition of the channels at the time the measurements were made. Mention is made of all sorts of growth, obstructions, and débris—factors which are in many instances responsible for the high values of n obtained. The pronounced effect of vegetation, such as grass, in a channel is clearly shown by the experiments made on three of the channels in North Carolina (Table 5); of the effect of small growth, such as weeds, bushes, saplings, and trees, by the experiments in Lee County Miss., in Arkansas, in Missouri, and in Illinois (Tables 1, 7, 8, and 9); and of the effect of large obstructions, such as logs, fallen trees, and débris, by the experiments on the South Forked Deer River at Campbell's levee, near Jackson, Tenn. (Table 3). Whether or not much erosion has taken place in the channel is also mentioned under this heading.

WHEN CONSTRUCTED

The age of the channel at the time the experiments were made may be obtained by referring to this heading and to column 2; the former shows approximately when the channel was constructed and the latter the date when the experiments were made. The time elapsed since the construction of a dredged channel is to some extent a measure of the condition of the channel as regards growth and other obstructions to flow, except where the channel has been carefully maintained. It is also a measure of the probable extent of erosion or silting that has occurred in the channel since construction. The growth of vegetation in a channel checks erosion and promotes silting, but on the other hand active erosion in a channel checks and often entirely prevents the growth of vegetation.

Low values of n are generally found for properly finished, newly dredged channels of uniform cross section, as was the case for Mud Creek (Table 1) and South Forked Deer River near Roberts, Tenn. (Table 3). The effect of erosion on such a channel is to make it more irregular and thereby to increase the value of n. However, after a certain amount of erosion has taken place it does not necessarily follow that further erosion will tend to increase the irregularity of the channel, as may be seen from the results obtained for the North Forked Deer River near Trenton, Tenn. (Table 3).

ACCURACY OF RESULTS

With few exceptions there are no reasons to suspect inaccuracies in the result of these experiments. The gaging sections and slope courses were so selected as to remove as far as possible the probability of large errors in the field measurements. In some instances, which will be mentioned under the separate discussion of each channel, favorable sites for gaging stations and slope courses were not obtained. Where no mention is made as to the reliability of the results, it may be inferred that the results obtained are entirely reliable. Comparatively speaking, the most accurate results were obtained for the high stages in the various channels, since there was a greater probability of error in the gagings and cross-sectional measurements for the lower stages.

DESCRIPTION OF EXPERIMENTS

A description of the nine sets of experiments and a discussion of the results obtained are given in the following pages.

EXPERIMENTS IN LEE COUNTY, MISS.

Experiments were conducted on five dredged channels in Lee County, Miss., namely; Old Town Creek, Mud Creek, Twenty Mile Creek, Coonewah Creek, and Chawappah Creek. (Table 1.) The topography of these watersheds is rolling and somewhat hilly.

OLD TOWN CREEK

Measurements were made on this channel early in 1913 and in 1914. A straight course of 1,224 feet below the steel highway bridge, one-half mile east of Tupelo, Miss., was selected for making the measurements. The discharge measurements for 1913 were made from the highway bridge and those for 1914 from a suspension footbridge constructed near the upper end of the course. The latter gaging section was much more desirable for accurate measurements than the former one.

An experiment for determining the effect upon the flow in the channel, due to the clearing of brush and other resistances to flow, was conducted on Old Town Creek. No clearing was done for the measurements during 1913. One side slope of the channel and part of the bottom were practically covered with small saplings, brush, and cane, and were quite irregular. The other side slope was comparatively smooth and uniform. For the measurements during 1914 all brush, logs, and other obstructions were cleared from the course of the channel and for 500 feet above the upper end and for the same distance below the lower end of the slope course, so that a comparison could be made as to the relative values of n before and after clearing. The slope of the left bank was quite regular while that of the right bank was extremely irregular, a condition due to the growth of brush causing the bank to erode unevenly. The soil in the bottom and sides of the ditch was quite hard. The views shown in Plate 1 give a good idea of the conditions existing in the channel before and after clearing. (See also fig. 1, A, for average cross section of the channel.)

TABLE 1.—*Results of experiments made in Lee County, Miss.*

OLD TOWN CREEK DREDGED CHANNEL NEAR TUPELO, MISS. (BEFORE CLEARING), 1913

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
		Feet	*Feet*	*Second-feet*	*Sq. ft.*	*Ft. per sec.*	*Feet*				
1	Mar. 4, 1913	5.4	22.9	95.3	76.2	1.25	2.90	0.000518	32.2	0.055	*Course,* straight; 1,224 feet long. *Cross section,* slight and gradual variations in shape; for variation in size, see fig. 2, A. *Side slopes,* right side irregular, left side very irregular. *Bottom,* irregular and uneven. *Soil,* varies from black waxy clay at top to yellow clay at bottom. *Condition,* right side slope and part of bottom practically covered with small saplings, brush, and cane; occasional growths of vegetation on other side slopes. *Constructed,* Dec. 1907. (Pl. 1, A and fig. 1, A.)
2	Mar. 3, 1913	5.8	22.0	125.7	85.5	1.47	3.12	.000513	36.8	.049	
3	Mar. 24, 1913	6.7	25.9	179.6	108.2	1.66	3.55	.000444	41.8	.045	
4	Mar. 21, 1913	10.8	34.9	500.7	231.8	2.16	5.30	.000388	47.6	.043	
5	Apr. 4, 1913	11.7	35.5	579.4	261.0	2.22	5.78	.000445	43.8	.048	
6	Feb. 27, 1913	12.6	39.0	674.0	298.2	2.26	5.95	.000452	43.5	.049	
7	Mar. 14, 1913	13.6	45.2	823.0	341.5	2.41	6.06	.000375	50.5	.042	
	----------	[1] 13.0	----------	----------	----------	----------	----------	----------	----------	----------	

OLD TOWN CREEK DREDGED CHANNEL NEAR TUPELO, MISS. (AFTER CLEARING), 1914

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
8	Mar. 5, 1914	4.0	19.5	45.0	50.0	0.90	2.28	0.000358	31.5	0.052	Description of channel practically the same as the above, except for remarks under *Condition.* *Condition,* all brush, vegetation, and obstructions to flow were cleared from the course of channel and for 500 feet above the upper end of the course, and for the same distance below the lower end. (Pl. 1, B.)
9	Mar. 20, 1914	4.3	20.0	59.7	58.0	1.03	2.43	.000350	35.3	.047	
10	Apr. 17, 1914	4.65	21.0	77.9	60.4	1.29	2.55	.000377	41.6	.041	
11	Apr. 9, 1914	5.3	22.2	105.4	74.2	1.42	2.85	.000292	49.2	.035	
12	Apr. 3, 1914	5.4	23.0	120.0	80.0	1.50	2.90	.000312	49.8	.035	
13	Apr. 13, 1914	6.6	26.4	185.1	107.0	1.73	3.37	.000271	57.4	.032	
14	Mar. 26, 1914	6.7	26.5	218.2	110.2	1.98	3.42	.000305	61.4	.030	
15	Mar. 12, 1914	7.1	27.5	240.0	120.0	2.00	3.53	.000290	62.5	.029	
16	Mar. 26, 1914	7.1	27.6	242.4	120.0	2.02	3.58	.000279	64.0	.029	
17	do	7.4	28.0	260.4	127.0	2.05	3.69	.000267	65.3	.029	
18	Apr. 13, 1914	8.1	29.8	310.2	142.3	2.18	3.95	.000271	66.6	.028	
19	May 5, 1914	11.6	37.5	710.2	265.0	2.68	5.70	.000346	60.3	.034	
20	Mar. 30, 1914	12.4	39.7	815.6	295.5	2.76	5.95	.000268	69.1	.030	
21	May 6, 1914	12.7	41.0	882.2	307.4	2.87	6.05	.000346	62.8	.033	
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MUD CREEK DREDGED CHANNEL NEAR TUPELO, MISS.

22	Apr. 11, 1914	2.6	18.5	54.8	40.0	1.37	1.8	0.000300	59.0	0.027	*Course*, straight; 1,194 feet long. *Cross section*, very little variation in shape; for variation in size see fig. 2, B. *Side slopes*, quite regular. *Bottom*, even and regular. *Soil*, sandy, waxlike clay. *Condition*, newly dredged channel; no vegetation or obstructions of any sort in channel. *Constructed*, January, 1913. (Pl. 1, C and fig. 1, B.)
23	do	2.8	19.3	61.9	43.0	1.44	1.9	.000305	59.8	.027	
24	Apr. 7, 1914	2.9	19.5	64.8	43.2	1.50	1.9	.000305	62.3	.026	
25	Apr. 9, 1914	3.2	20.5	74.9	47.7	1.57	2.1	.000310	61.5	.027	
26	Apr. 5, 1914	3.8	22.0	115.0	57.5	2.00	2.3	.000301	76.0	.022	
27	Mar. 28, 1914	4.0	22.6	125.0	61.0	2.05	2.5	.000349	69.3	.025	
28	Mar. 26, 1914	4.1	22.8	130.2	62.6	2.08	2.6	.000336	70.4	.025	
29	do	4.9	24.7	192.7	88.0	2.19	2.9	.000321	71.8	.025	
30	Mar. 27, 1914	4.95	24.8	199.1	88.5	2.25	2.9	.000349	70.7	.025	
31	Apr. 8, 1914	5.0	24.9	203.4	90.0	2.26	3.0	.000340	70.8	.025	
32	May 5, 1914	9.9	32.5	762.8	225.0	3.39	5.3	.000364	77.2	.026	
33	Mar. 29, 1914	10.65	34.5	904.0	252.5	3.58	5.6	.000378	77.8	.026	
34	do	10.70	34.5	914.4	254.0	3.60	5.6	.000393	76.8	.026	
		[1] 11.50									

TWENTY MILE CREEK DREDGED CHANNEL NEAR BALDWYN, MISS.

35	Mar. 28, 1913	4.5	24.0	120.0	75.5	1.59	2.75	0.000194	68.9	0.025	*Course*, straight; 324 feet long. *Cross section*, slightly abrupt variations in shape; for variation in size, see fig. 2, C. *Side slopes*, lower, quite regular; upper, quite irregular, due to caving of banks. *Bottom*, quite even and regular. *Soil*, waxy clay loam; contains some sand. *Condition*, channel practically free from vegetation; great many roots along upper part of channel; erosion very active during high stages. *Constructed*, January, 1910. (Pl. 2, A and fig. 1, C.)
36	Mar. 27, 1913	6.4	30.8	288.1	124.7	2.31	3.60	.000382	62.3	.030	
37	Apr. 10, 1913	12.1	40.0	1,312.8	328.2	4.00	6.50	.000800	55.5	.038	
38	do	[1] 13.7	42.4	1,730.3	384.5	4.50	7.15	.001150	49.6	.044	

CHAWAPPAH CREEK DREDGED CHANNEL NEAR SHANNON, MISS.

39	Feb. 5, 1913	2.8	18.7	75.0	41.0	1.83	1.95	0.000850	44.9	0.036	*Course*, straight; 320 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 2, D. *Side slopes*, quite regular except near top and along edge of bottom. *Bottom*, quite regular. *Soil* varies from a sandy loam at top to a waxy clay at bottom. *Condition*, very little vegetation in channel; irregularity of upper part of channel due to erosion. *Constructed*, May, 1911. (Pl. 2, B and fig. 1, D.)
40	Apr. 5, 1913	7.3	31.2	368.1	156.0	2.36	4.20	.000406	57.1	.034	
41	Feb. 28, 1913	11.1	36.4	1,152.6	282.5	4.08	6.05	.000935	54.2	.038	
		[1] 12.0									

COONEWAH CREEK DREDGED CHANNEL NEAR SHANNON, MISS.

42	Apr. 4, 1913	10.6	36.7	850.0	286.2	2.97	5.95	0.000620	48.9	0.043	*Course*, straight; 450 feet long. *Cross section*, rather gradual variations in shape; for variations in size, see fig. 2, E. *Side slopes*, very irregular. *Bottom*, irregular and uneven. *Soil*, clay loam. *Condition*, some grass and other vegetation on side slopes; bottom free from growth. *Constructed*, May, 1909. (Pl. 2, C and fig. 1, E.)
		[1] 12.0									

[1] Average maximum depth at bankful stage.

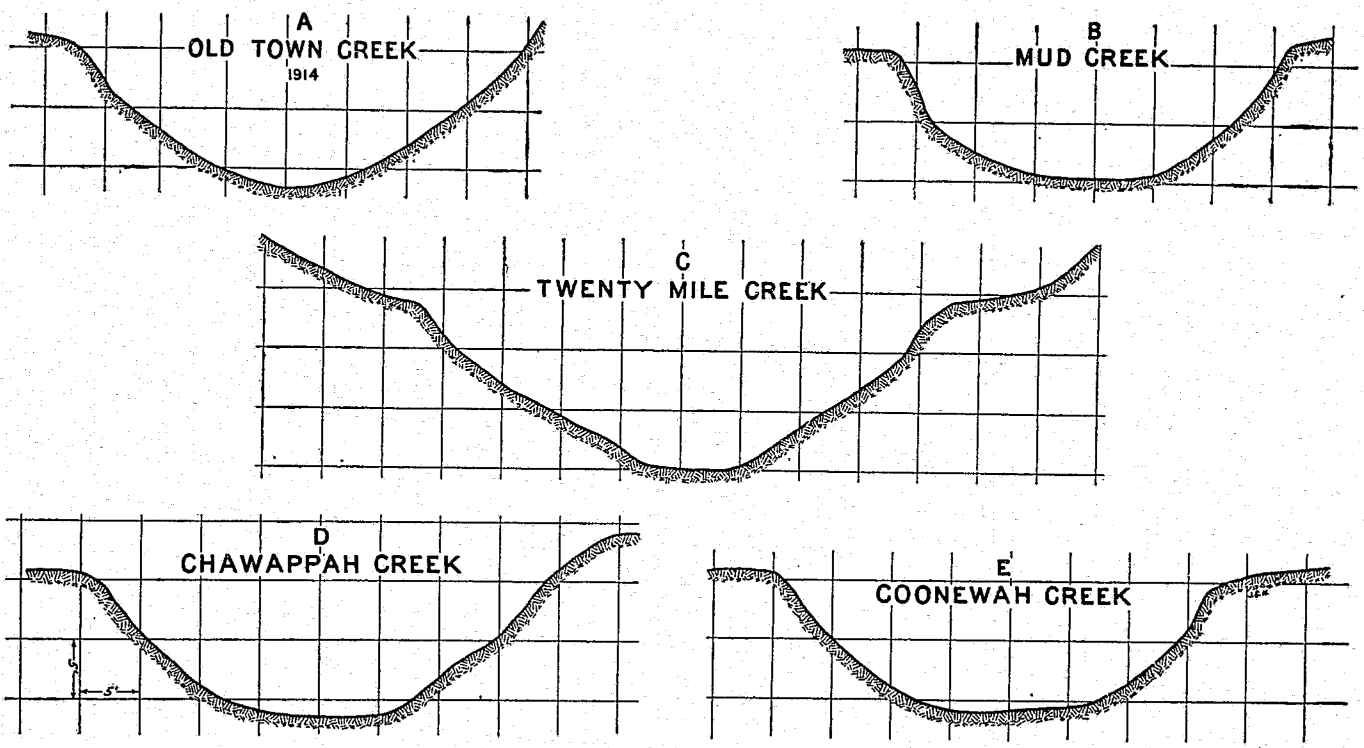


FIGURE 1.—Average cross sections of channels for experiments in Lee County, Miss.

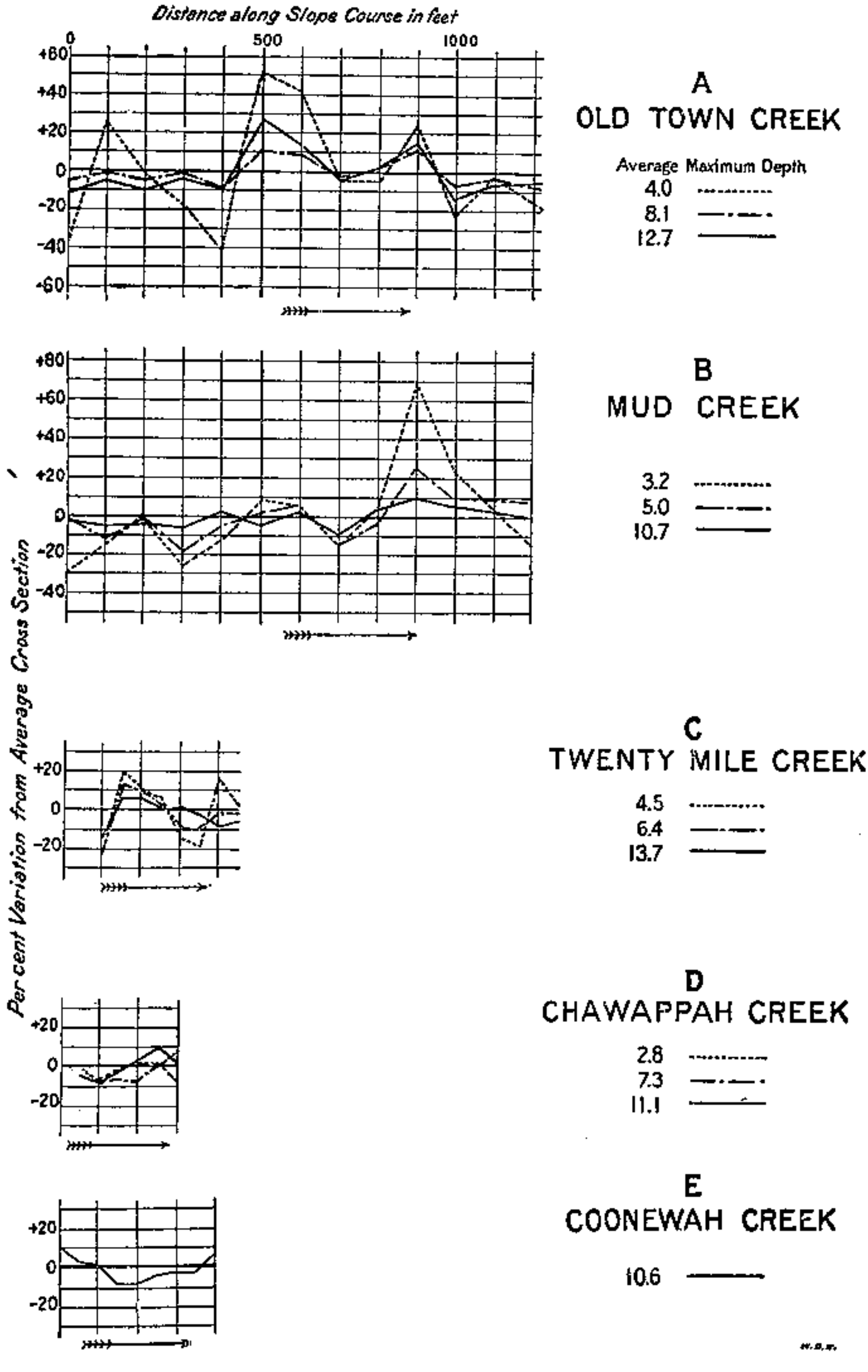


FIGURE 2.—Graphs for experiments in Lee County, Miss., showing per cent variation from average cross-sectional area, for all cross sections along slope courses

In Table 1, measurements 1 to 21, are given the values obtained for *n*, together with the various observed hydraulic elements. It is obvious, from the values of *n* obtained before and after clearing, that the efficiency of a channel is greatly decreased by permitting the growth of vegetation in it.

During low water the uniform fall of the surface of the water was interrupted by irregularities in the bottom and sides of the channel. For such conditions the hydraulic grade throughout the section consisted of a series of comparatively steep slopes followed by flatter ones, due to the depth of water being so small that the irregularities in the channel gave rise to quite appreciable variations in area of cross section from point to point, thus causing variations in velocity and in the hydraulic grade. (Fig. 2, A.) As a result the values of *n* obtained for low water conditions are high. The total loss of head throughout the course under such conditions is the sum of the loss due to the roughness of the wetted perimeter and the quite appreciable losses in shock and eddies that occur where the hydraulic gradient changes from a steeper to a flatter slope and where the cross section of flow changes. For low water conditions the loss in shock and eddies is quite appreciable, and as the values of *n* were obtained by directly measuring this total loss of head throughout the course these values would be necessarily large. The table shows that for such conditions the value of *n* decreases as the depth increases. This would be expected, for as the depth increases the second factor mentioned above becomes comparatively smaller, and the total loss of head thus becomes to a greater extent due to roughness of wetted perimeter and to a less extent due to the influence of eddies and shock.

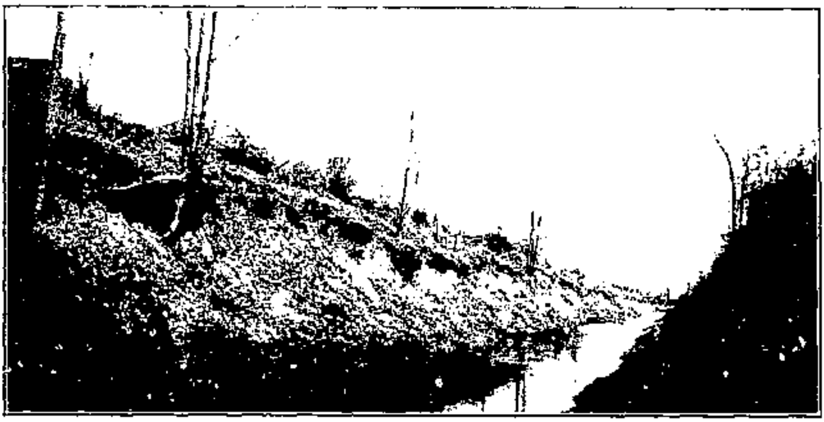
MUD CREEK

Measurements were made on this channel during the early part of the year 1914. For the slope measurements a straight course 1,194 feet long was selected above the highway bridge about 1 mile east of Tupelo. A suspension footbridge was constructed at a site where conditions were ideal for making accurate current meter measurements.

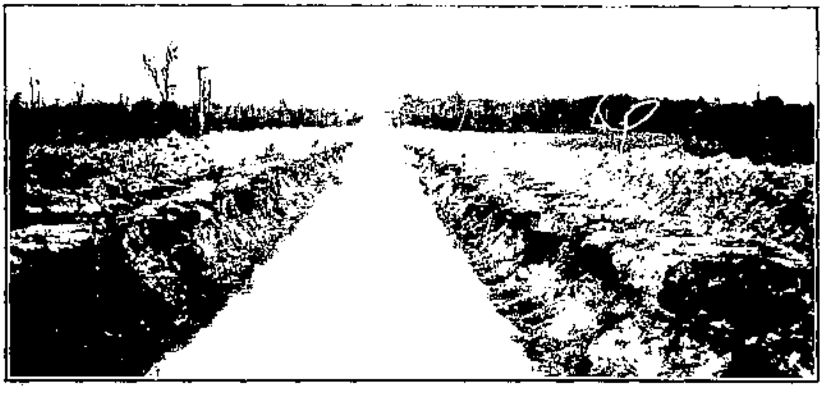
A good idea of the condition and regularity of the channel can be obtained from Plate 1, C. Although in the same valley, the soil is decidedly different from that found in Old Town Creek. This part of the bottom land is made up of sediment carried from the eastern part of the Mud Creek watershed, where the soil contains considerable sand. The soil in the channel is a sandy, waxlike clay that erodes very easily. This was a comparatively new channel at the time of these experiments, the ditch having been finished in January, 1913; and, although it had eroded to some extent, it had retained its original uniform slope and comparatively uniform cross-sectional area. (Figs. 1, B and 2, B.)

In Table 1, measurements 22 to 34, are shown the various hydraulic elements of Mud Creek as computed from field measurements, and the values of *n* obtained. That for all stages of Mud Creek is about 0.025, while that obtained for the higher stages in Old Town Creek, after clearing, is about 0.030. The lower value of *n* as obtained for Mud Creek can readily be ascribed to the facts that this is a more recently constructed channel and that the bottom slope and cross-sectional area are more uniform throughout the course than for Old Town Creek.

A

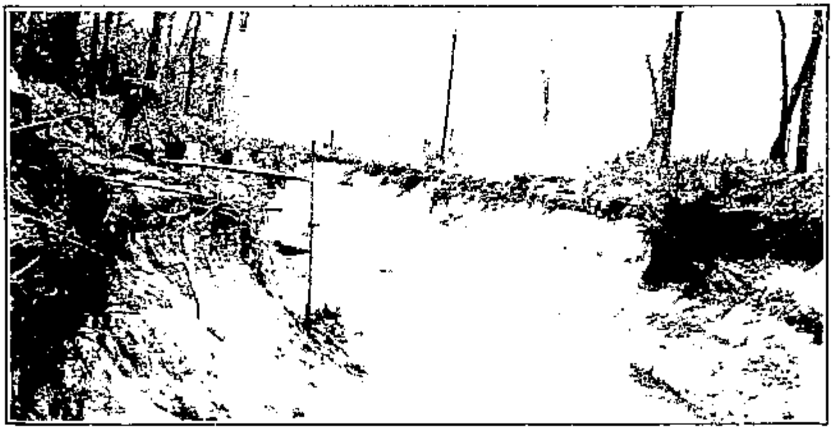


B

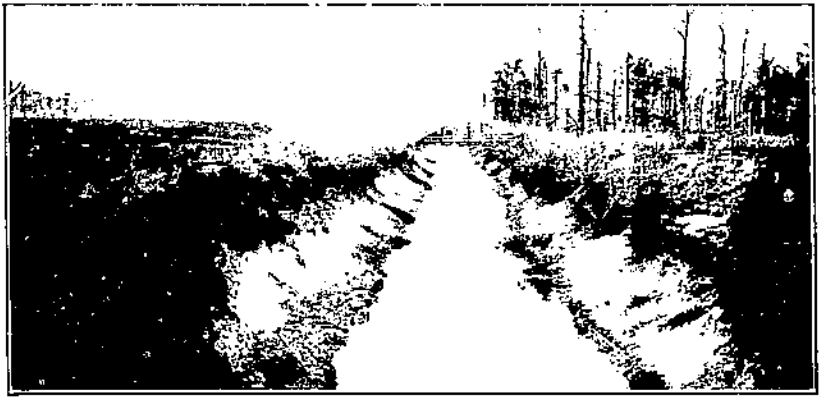


C

A, Old Town Creek dredged channel near Tupelo, Miss., looking up slope course, before clearing, 1913; B, Same view as A above after clearing, 1914; C, Mud Creek dredged channel near Tupelo, Miss., looking up slope course, 1913. (See Table 1)



A



B

C

A, Twenty Mile Creek dredged channel near Baldwyn, Miss., looking down slope course, 1913; B, Chawappah Creek dredged channel near Shannon, Miss., looking up slope course, 1913; C, Coonewah Creek dredged channel near Shannon, Miss., looking down slope course, 1913. (See Table 1)

TWENTY MILE CREEK

The slope course on Twenty Mile Creek was rather short, being 324 feet in length, and was located below the highway bridge 1 mile east of Baldwyn, Miss. (Pl. 2, A, and figs. 1, C and 2, C.) The lower part of the channel was quite smooth and regular, but the upper part and edge of bank were irregular. The channel is eroding rapidly, and many stumps along the banks have been undermined and fallen into the channel. Table 1 shows the hydraulic elements and the values of n obtained for Twenty Mile Creek. The value of n increases as the stage increases, due no doubt to the irregularities in the wetted perimeter for the higher stages. The soil in the channel is a waxy clay loam, and in some parts of the channel contains considerable sand.

CHAWAPPAH CREEK

Slope measurements for Chawappah Creek were made on a rather short course (320 feet long) between the highway and railroad bridges, one-half mile south of Shannon, Miss. The gaging section was located at the highway bridge. The view of Chawappah Creek for low water (pl. 2, B), shows very well the condition of the channel. The soil varies from a sandy loam to a waxy clay, and the sides and bottom were quite hard. The channel is eroding very rapidly, which is partly the cause of the turbulent water surface and the resulting comparatively high values of n. The average value obtained for n was about 0.035. (Figs. 1, D and 2, D.)

COONEWAH CREEK

Only one observation for slope was made on Coonewah Creek. The value computed for n was 0.043. Plate 2, C, shows the course on which the slope was measured and the condition of the channel. The soil is quite similar to that found on Chawappah Creek, but erosion has not been as active as on the latter. (Figs. 1, E and 2, E.)

DISCUSSION OF LEE COUNTY EXPERIMENTS

Of the experiments made in Lee County, Miss., the results obtained from those on Old Town and Mud Creeks are the most reliable. It appears that for conditions of flow the value of n for channels similar to Mud Creek is 0.025, which means that the bottom and sides should be fairly regular and free from any form of obstruction to flow, and the slope and cross-sectional area practically uniform. These conditions generally obtain only in new ditches, and it would therefore not be wise to use a coefficient as low as 0.025 in the design of channels, since the efficiency of a channel generally decreases with age, as is shown by the experiments on Old Town Creek. Also, erosion tends to increase irregularities in new channels, which results in an increasing roughness coefficient, so it is not believed advisable to use a value of n less than 0.035 in the design of small ditches in this and similar sections of the country.

EXPERIMENTS IN WASHINGTON AND BOLIVAR COUNTIES

Experiments in Washington and Bolivar Counties, Miss., were conducted during 1914 and 1915 and again during 1924 to 1926. The first set of experiments were made on the following channels: Bogue

Phalia near Helm, Bogue Hasty, Pecan Bayou, West Bogue Hasty, and East Bogue Hasty. The second set were made on Bogue Phalia near Heads, Bogue Hasty, West Bogue Hasty, Horseshoe Bayou, Ditch No. 1, and Snake Creek. The channel of West Bogue Hasty was redredged between the time of the first and second sets of experiments. The topography of the watersheds of these streams is comparatively flat, the fall of the land being about 1 foot per mile.

BOGUE PHALIA NEAR HELM

The conditions for the accurate discharge and slope measurements on this channel were ideal. A straight course of practically uniform cross section was selected for slope measurements, about half a mile above the Yazoo & Mississippi Valley Railroad bridge, 2 miles from Helm. The length of the course was 1,003 feet. The gaging station was located near the lower end of the course, and the velocity measurements were made from a movable car suspended from a steel cable which was stretched across the stream at right angles to the direction of flow and supported by upright poles on either bank.

The left side slope of Bogue Phalia, along the course, was quite regular while the right side was subject to caving and was only fairly regular. The channel was very smooth for low stages and of uniform section for all stages. (Fig. 4, A.) Very little vegetation of any sort was found in the channel. (Pl. 3, A and fig. 3, A.) The soil in the lower part of the channel is sandy. The soil in the upper part is a clay loam of close texture and is quite susceptible to caving, particularly when wet.

The slope was indeed an extremely variable quantity. No two measurements of slope were found to be the same, due to the backwater conditions. The greatest slope was found for the lowest stage, and the others varied according to the effect of backwater at the time that measurements were made.

The principal hydraulic elements of the channel and the values of C and n obtained therefrom are shown in Table 2. Little variation was found in the values of C, and the values of n were found to vary from 0.022 for the lowest stage to 0.031 for the highest stages. As would be expected, the values of n were found to be low for the lower stages, where the channel was quite smooth and uniform in section, and higher for the higher stages, where a greater resistance was offered to flow, by the rougher and more irregular sides of the channel. On the whole, it can be said that this channel was in excellent shape, a fact which is substantiated by the comparatively low values of n obtained.

BOGUE PHALIA NEAR HEADS

Gagings of this channel were made from a single-span highway bridge about 1½ miles southwest of Heads, Miss. The slope course was 1,554 feet long, with a slight curve at the lower end. Conditions were good for obtaining accurate discharge and slope measurements. At high stages the water had very little velocity for a distance of 30 to 40 feet from the banks.

47184°—29——2

TABLE 2.—*Results of experiments made in Washington and Bolivar Counties, Miss.*

BOGUE PHALIA DREDGED CHANNEL, NEAR HELM, MISS.

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
		Feet	*Feet*	*Second-feet*	*Sq. ft.*	*Ft. per sec.*	*Feet*				
1	Jan. 14, 1915	4.20	57.5	468.5	192.0	2.44	3.11	0.000297	80.2	0.022	*Course*, straight; 1,003 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 4, A. *Side slopes*, left side, quite regular; right side, fairly regular. *Bottom*, smooth and even. *Soil*, lower part, sandy clay loam; upper part, clay loam of close texture. *Condition*, excellent, very little vegetation of any sort; lower part of channel more uniform and regular than upper part. *Constructed*, May, 1913. (Pl. 3, A and fig. 3, A.)
2	Feb. 13, 1915	6.20	63.3	678.4	320.0	2.12	4.61	.000159	78.3	.025	
3	Feb. 11, 1915	8.05	68.5	906.4	440.0	2.06	5.79	.000132	74.5	.028	
4	Feb. 10, 1915	9.45	72.5	1,102.1	535.0	2.06	6.65	.000118	73.6	.029	
5	Feb. 9, 1915	10.85	76.5	1,363.2	640.0	2.13	7.49	.000104	76.3	.029	
6	Jan. 27, 1915	11.10	77.3	1,635.9	657.0	2.49	7.67	.000127	79.9	.027	
7	Feb. 8, 1915	12.20	79.8	1,650.0	750.0	2.20	8.38	.000102	75.3	.030	
8	Feb. 2, 1915	14.80	86.1	3,142.8	970.0	3.24	10.00	.000195	73.3	.031	
9	Feb. 4, 1915	14.80	86.1	2,929.4	970.0	3.02	10.00	.000165	74.3	.031	
	-------	[1] 18.00	-------	-------	-------	-------	-------	-------	-------	-------	

BOGUE PHALIA NATURAL CHANNEL, NEAR HEADS, MISS.

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
10	Mar. 15, 1926	8.8	121	944	756	1.25	6.09	0.000072	59.7	0.036	*Course*, nearly straight, slight curve at lower end; 1,554 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 4, B. *Side slopes*, very irregular. *Bottom*, irregular and uneven. *Soil*, clay loam, sandy bottom. *Condition*, weeds and small trees along banks; natural channel; was cleaned of all growth and obstructions in 1915. (Pl. 3, B and fig. 3, B.)
11	Nov. 17, 1925	10.4	132	1,080	965	1.12	7.10	.000056	56.2	.041	
12	Mar. 7, 1926	11.8	142	2,867	1,157	2.48	7.92	.000214	60.2	.037	
13	Mar. 9, 1926	12.5	147	2,383	1,260	1.89	8.32	.000106	63.6	.036	
14	Jan. 22, 1926	12.8	150	2,875	1,310	2.19	8.51	.000139	63.7	.036	
15	Mar. 8, 1926	13.5	154	3,064	1,405	2.18	8.84	.000132	63.8	.036	
16	Feb. 29, 1924	14.3	160	3,192	1,527	2.09	9.25	.000109	65.8	.036	
17	Dec. 17, 1925	14.5	162	3,000	1,550	1.94	9.32	.000112	60.0	.040	
18	Feb. 28, 1924	15.6	168	4,033	1,751	2.30	10.06	.000136	62.2	.038	
	-------	[1] 20.0	-------	-------	-------	-------	-------	-------	-------	-------	

BOGUE HASTY DREDGED CHANNEL, NEAR SHAW, MISS., 1915

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
19	Jan. 5, 1915	2.55	38.1	50.1	74.8	0.67	1.85	0.000152	39.9	0.038	*Course*, straight; 1,039 feet long. *Cross section*, slight and gradual variations in shape; for variations in size, see fig. 4, C. *Side slopes*, right side very irregular and caving badly; left side quite regular. *Bottom*, rather irregular. *Soil*, upper part, dark silty loam; lower part, light yellow clay. *Condition*, upper part right side slope covered with weeds and small tree sprouts; left side slope practically free from vegetation. *Constructed* September, 1911. (Pl. 4, A and fig. 3, C.)
20	Jan. 20, 1915	4.05	42.3	183.6	137.0	1.34	3.01	.000183	57.1	.031	
21	Feb. 25, 1915	5.60	47.2	275.9	209.0	1.32	4.08	.000119	59.8	.032	
22	Feb. 22, 1915	5.75	47.3	366.8	210.8	1.74	4.10	.000166	66.7	.028	
23	Feb. 23, 1915	7.80	53.3	650.0	314.0	2.07	5.30	.000169	69.2	.029	
24	Jan. 25, 1915	[1] 9.50	58.2	786.6	414.0	1.90	6.31	.000157	60.4	.035	

[1] Average maximum depth at bankful stage.

TABLE 2.—*Results of experiments made in Washington and Bolivar Counties, Miss.*—Continued

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
	BOGUE HASTY DREDGED CHANNEL, NEAR SHAW, MISS., 1924–1926										
		Feet	*Feet*	*Second-feet*	*Sq. ft.*	*Ft. per sec.*	*Feet*				
25	Mar. 13, 1926	4.2	40.4	134	117	1.15	2.77	0.000130	60.6	0.029	*Course*, straight, 1,000 feet long, nearly same as above. *Cross section*, slight variation in shape; for variation in size, see fig. 4, D. *Side slopes*, fairly even and regular. *Bottom*, rather irregular. *Soil*, same as above. *Condition*, banks fairly clean and free from vegetation. *Constructed*, September, 1911. (Pl. 4, B and fig. 3, D.)
26	Mar. 9, 1926	5.4	44.5	204	169	1.21	3.59	.000114	59.8	.031	
27	Apr. 17, 1924	5.9	45.7	319	184	1.73	3.79	.000147	73.3	.026	
28	Dec. 17, 1925	7.7	52.0	391	286	1.37	5.14	.000099	60.7	.034	
29	Mar. 8, 1926	7.7	52.0	465	287	1.62	5.15	.000140	60.3	.034	
30	May 28, 1924	8.4	54.2	586	323	1.81	5.55	.000120	70.1	.029	
31	Feb. 25, 1924	9.4	56.5	710	373	1.90	6.06	.000135	66.4	.032	
	----------	[1] 9.5	----------	----------	----------	----------	----------	----------	----------	----------	
	PECAN BAYOU DREDGED CHANNEL, NEAR SHAW, MISS.										
32	Feb. 25, 1915	4.35	20.8	36.5	67.5	0.54	2.79	0.0000256	63.9	0.027	*Course*, straight; 665 feet long. *Cross section*, slight and gradual variations in shape; for variation in size, see fig. 4, E. *Side slopes*, fairly regular except near the top. *Bottom*, even and regular. *Soil*, dark-colored waxy clay. *Condition*, a few weeds in channel; upper part of channel quite irregular. *Constructed*, July, 1911. (Pl. 3, C and fig. 3, E.)
33	Feb. 22, 1915	4.45	21.0	53.2	70.0	.76	2.85	.0000676	54.7	.032	
34	Feb. 24, 1915	5.85	23.5	52.3	102.6	.51	3.63	.0000271	51.3	.037	
35	do	6.35	24.3	68.1	113.5	.60	3.82	.0000271	59.0	.033	
36	Feb. 23, 1915	[1] 6.95	25.5	110.9	127.5	.87	4.04	.0000782	49.0	.040	
	WEST BOGUE HASTY DREDGED CHANNEL, NEAR SHAW, MISS., 1914–15										
37	Feb. 21, 1915	2.55	26.5	32.5	59.0	0.55	2.22	0.0001110	35.0	0.046	*Course*, straight; 757 feet long. *Cross section*, slight variations in shape; for variation in size, see fig. 4, G. *Side slopes*, fairly regular. *Bottom* fairly regular. *Soil*, dark-colored waxy clay. *Condition*, channel in good condition with the exception of a few weeds; sediment deposited near lower end of course caused water to stand nearly whole length of course during periods of no flow. *Constructed*, May, 1911. (Pl. 5, A and fig. 3, G.)
38	Feb. 25, 1915	4.17	20.2	66.3	97.5	.68	2.97	.0000806	44.0	.040	
39	Dec. 31, 1914	5.75	32.3	81.5	143.0	.57	3.79	.0000515	40.8	.047	
40	Feb. 24, 1915	5.80	32.5	107.3	145.0	.74	3.82	.0000753	43.6	.044	
	----------	[1] 8.00	----------	----------	----------	----------	----------	----------	----------	----------	

WEST BOGUE HASTY DREDGED CHANNEL, NEAR SHAW, MISS., 1924–1926

41	May 13, 1926	4.1	36.8	55.2	106	0.52	2.75	0.0001315	27.3	0.062	*Course*, straight; 897 feet long. *Cross section*, slight variation in shape; for variation in size, see fig. 4, G. *Side slopes*, very irregular and uneven. *Bottom*, very irregular. *Soil*, dark colored, waxy clay with thin layers of fine sand which causes slides. *Condition*, very poor, due to caving banks and weeds and grass. *Constructed*, May, 1911; redredged, April, 1923. (Pl. 5, B and fig. 3, G.)
42	May 12, 1926	5.7	42.4	121.0	172	.70	3.79	.0001003	35.9	.053	
43	do	6.2	44.0	141.0	190	.74	4.03	.0000914	38.6	.050	
44	May 11, 1926	8.2	47.9	258.0	284	.91	5.31	.0000870	42.3	.050	
45	May 28, 1924	8.8	49.0	313.0	316	.99	5.72	.0000726	48.6	.044	
46	Feb. 27, 1924	9.4	52.0	402.0	344	1.17	5.91	.0000713	57.0	.038	
		[1] 10.0									

EAST BOGUE HASTY DREDGED CHANNEL, NEAR SHAW, MISS.

47	Mar. 31, 1915	2.51	16.6	20.1	30.5	0.66	1.69	0.000231	33.4	0.045	*Course*, straight; 502 feet long. *Cross section*, slight variations in shape; for variation in size, see fig. 4, H. *Side slopes*, slightly irregular. Bottom, fairly regular. *Soil*, dark-colored waxy clay. *Condition*, light growth of weeds on botton of channel; weeds, weed stubble, and roots on side slopes. *Constructed*, July, 1911. (Pl. 4, G and fig. 3, H.)
48	Feb. 25, 1915	4.61	22.2	80.5	72.5	1.11	2.81	.000211	43.7	.038	
49	Feb. 14, 1915	6.11	25.8	137.6	107.5	1.28	3.43	.000173	52.5	.035	
50	Dec. 31, 1914	[1] 6.41	26.4	149.5	115.0	1.30	3.58	.000249	43.5	.043	

HORSESHOE BAYOU DREDGED CHANNEL, NEAR CLEVELAND, MISS.

51	June 26, 1926	4.1	38.4	106.2	124.2	0.86	3.07	0.000218	33.2	0.053	*Course*, straight; 1,020 feet long. *Cross section*, slight variation in shape; for variation in size, see fig. 4, I. *Side slopes*, moderate irregularities caused by erosion and some caving of banks. *Bottom*, rather rough and irregular. *Soil*, stiff dark clay loam. *Condition*, a few short weeds in channel; 2 small bars in bottom where laterals enter. *Constructed*, December, 1921. (Pl. 5, C and fig. 3, I.)
52	May 11, 1926	4.0	38.2	120.4	120.6	1.00	3.00	.000130	50.6	.035	
53	do	4.8	40.1	178.0	153.0	1.16	3.58	.000131	53.6	.035	
54	Dec. 14, 1924	8.3	48.9	577.0	304.0	1.90	5.65	.000180	59.6	.035	
		[1] 9.0									

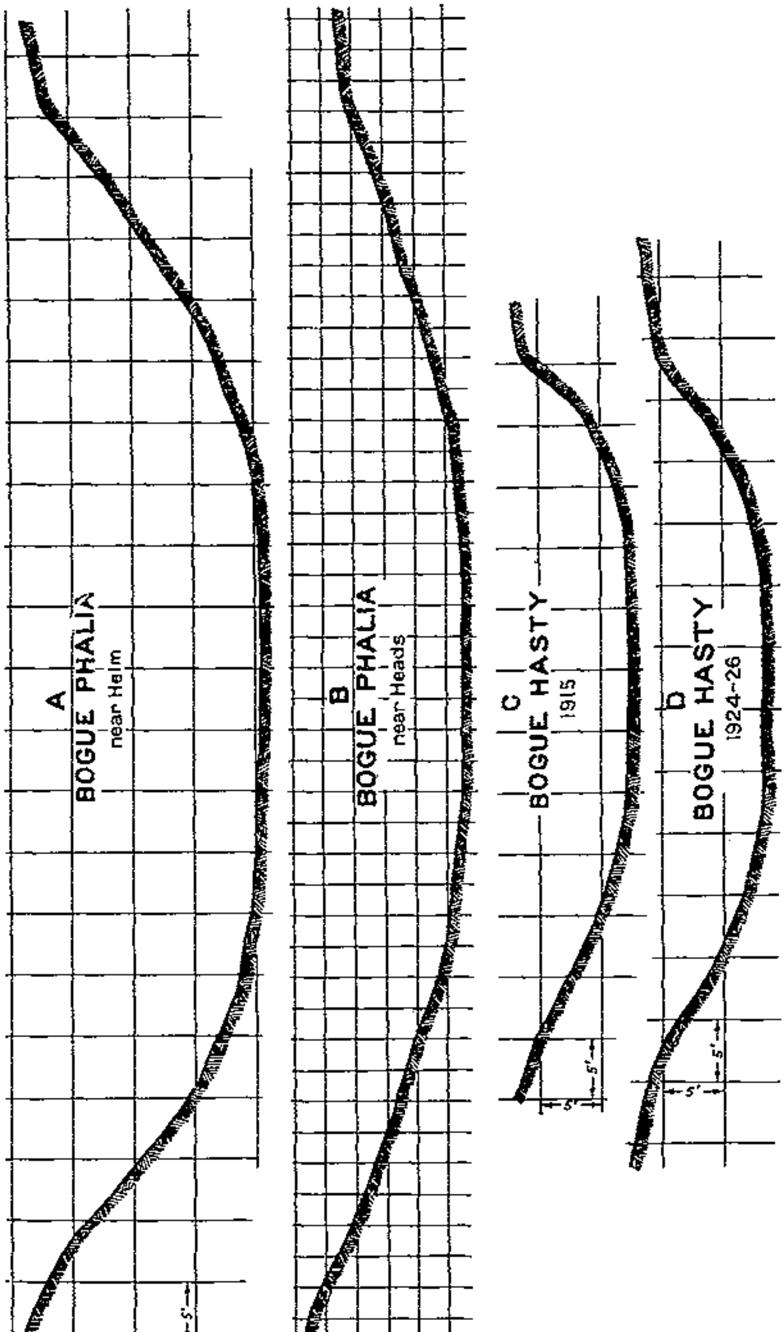
DREDGED DITCH NO. 1 NEAR SHAW, MISS.

55	Mar. 8, 1926	4.8	44.4	163.0	150.8	1.08	3.26	0.000184	44.1	0.041	*Course*, nearly straight; 995 feet long. *Cross section*, some variation in shape; for variation in size, see fig. 4, J. *Side slopes*, irregular, varying from steep to almost flat. *Bottom*, somewhat irregular. *Soil*, dark clay loam. *Condition*, growth of short grass and dead weeds in channel, perimeter rather rough. *Constructed*, February, 1922. (Pl. 6, A and fig. 3, J.)
56	Mar. 11, 1926	5.4	46.4	206.0	177.0	1.16	3.64	.000176	45.8	.041	
		[1] 8.0									

SNAKE CREEK DREDGED CHANNEL, NEAR VICTOR, MISS.

57	Feb. 27, 1924	8.6	45.3	343.0	233.0	1.47	4.79	0.000087	72.0	0.028	*Course*, straight; 1,000 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 4, K. *Side slopes*, quite regular. *Bottom*, fairly regular. *Soil*, stiff clay loam. *Condition*, practically no vegetation in channel, newly dredged. *Constructed*, February, 1924. (Pl. 6, B and fig. 3, K.)

[1] Average maximum depth at bankful stage.


A
BOGUE PHALIA
near Helm
5'
5'
B
BOGUE PHALIA
near Heads
5'
5'
C
BOGUE HASTY
1915
5'
5'
D
BOGUE HASTY
1924-26
5'
5'

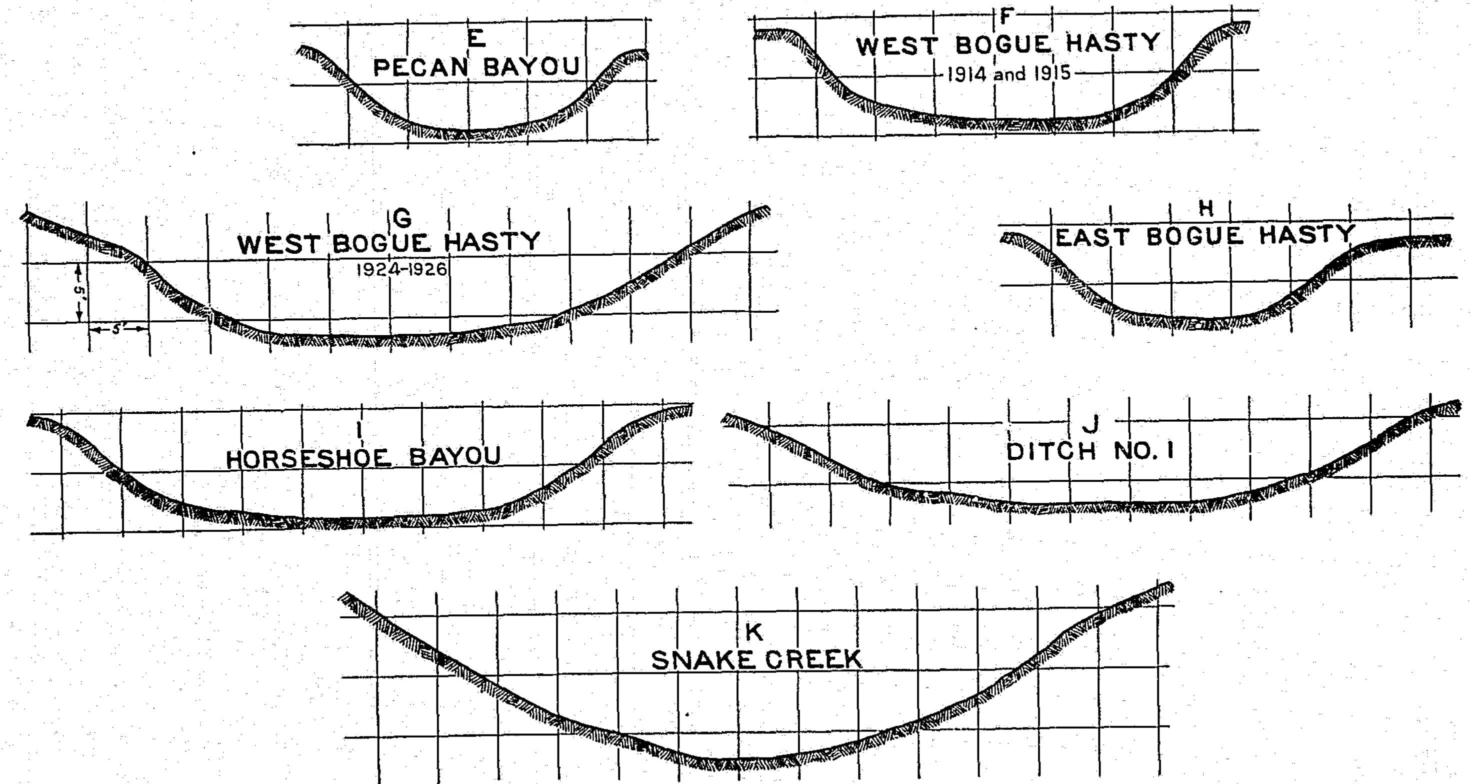


FIGURE 3.—Average cross sections of channels for experiments in Washington and Bolivar Counties, Miss.

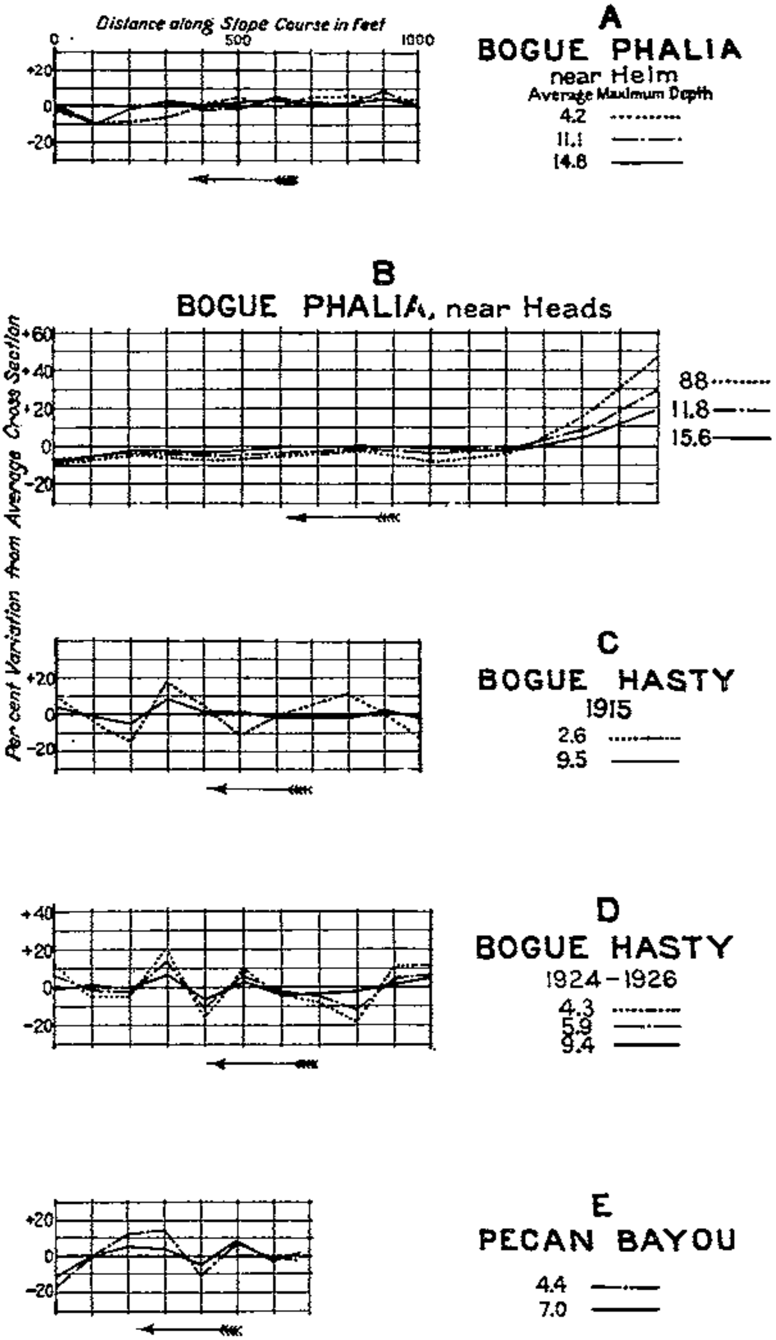
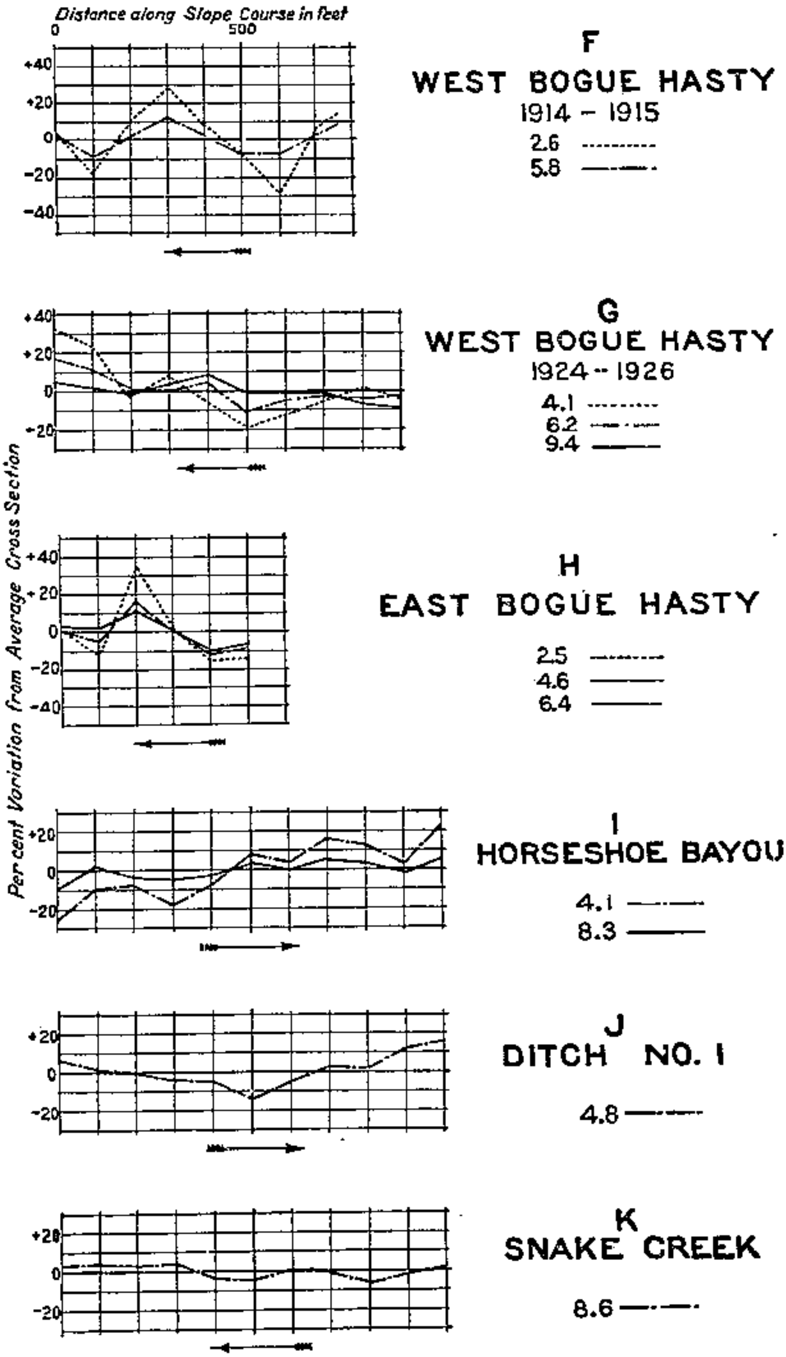


FIGURE 4.—Graphs for experiments in Washington and Bolivar Counties, Miss., showing



per cent variation from average cross-sectional area for all cross sections along slope courses

This is a natural channel, but was cleared of all growth and obstructions such as logs and fallen trees during the year 1915. There was considerable small tree growth along the banks (pl. 3, B), but practically no vegetation or obstructions in the bottom of the channel when these measurements were made. The cross section of the channel (fig. 3, B) was fairly uniform for about 1,200 feet from the lower end of the slope course, but along the upper 300 feet there was a rather marked increase in area. (Fig. 4, B.)

Table 2 shows that there was not much variation in the values of *n* obtained for different stages in the channel. No low-stage measurements were obtained, there being about 9 feet depth of water for the lowest stage and 15½ feet for the highest stage. It is believed that somewhat higher values of *n* would have been obtained for both higher and lower stages, judging from the condition of the channel.

BOGUE HASTY

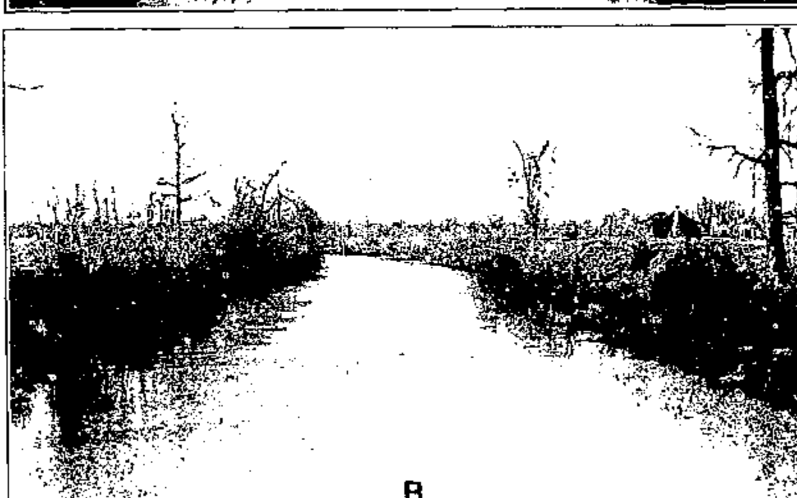
The course used for slope measurements on Bogue Hasty was 1,039 feet long for the experiments made during 1915. It was straight and fairly uniform (fig. 4, C) and no water through drain tile or surface ditches entered the channel along the course. It was located just above the highway bridge about 3 miles west of Shaw. The lower end of the course was above a slight bend in the channel and about 500 feet above the bridge. The gaging station, which consisted of a suspension footbridge (75-foot span), was placed near the lower end of the course. The conditions for both slope and discharge measurements were very good.

This channel was not in as good condition as that of Bogue Phalia, near Helm. The right-side slope was very irregular and was caving badly. The upper part was covered with weeds and small tree sprouts. The left-side slope was very regular and practically free from vegetation. (Pl. 4, A.) The soil in the upper part of the channel is a dark silty loam and in the lower part a light-yellow clay. It is sticky when wet and cracks and crumbles when dry. (See fig. 3, C for average cross section of channel.)

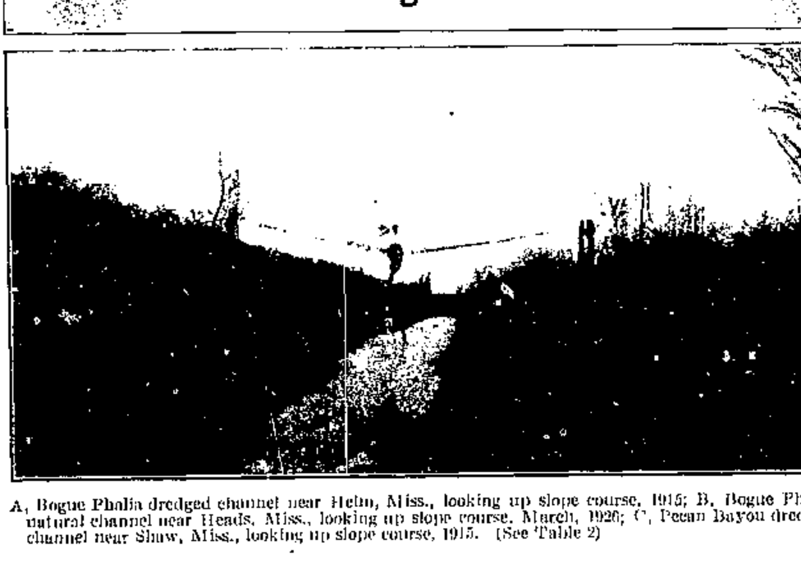
Table 2 shows the hydraulic elements and the values of *n* obtained from these experiments. The value of *n* (0.038) for extreme low stage is the highest obtained for this ditch, and is probably due to the irregularities in the bed of the channel. The values of *n* obtained for measurements 20 to 23, inclusive, are applicable to the lower half of the channel, and they agree quite closely with those obtained for Bogue Phalia dredged channel at medium to high stages, the conditions of smoothness and regularity of this part of the channel being very similar to the conditions of the Bogue Phalia channel. The values of *n* obtained for the higher stages of the channel are considerably higher than for the lower stages. The very irregular and caving right bank would lead one to expect a larger roughness coefficient for bankful stage than for the lower half.

Measurements on this channel were made also during the years 1924, 1925, and 1926. A slope course 1,000 feet long was selected at about the same location as the course used in 1915. Gagings were made from the highway bridge about 3 miles west of Shaw, Miss. Conditions for both slope and discharge measurements were good.

A

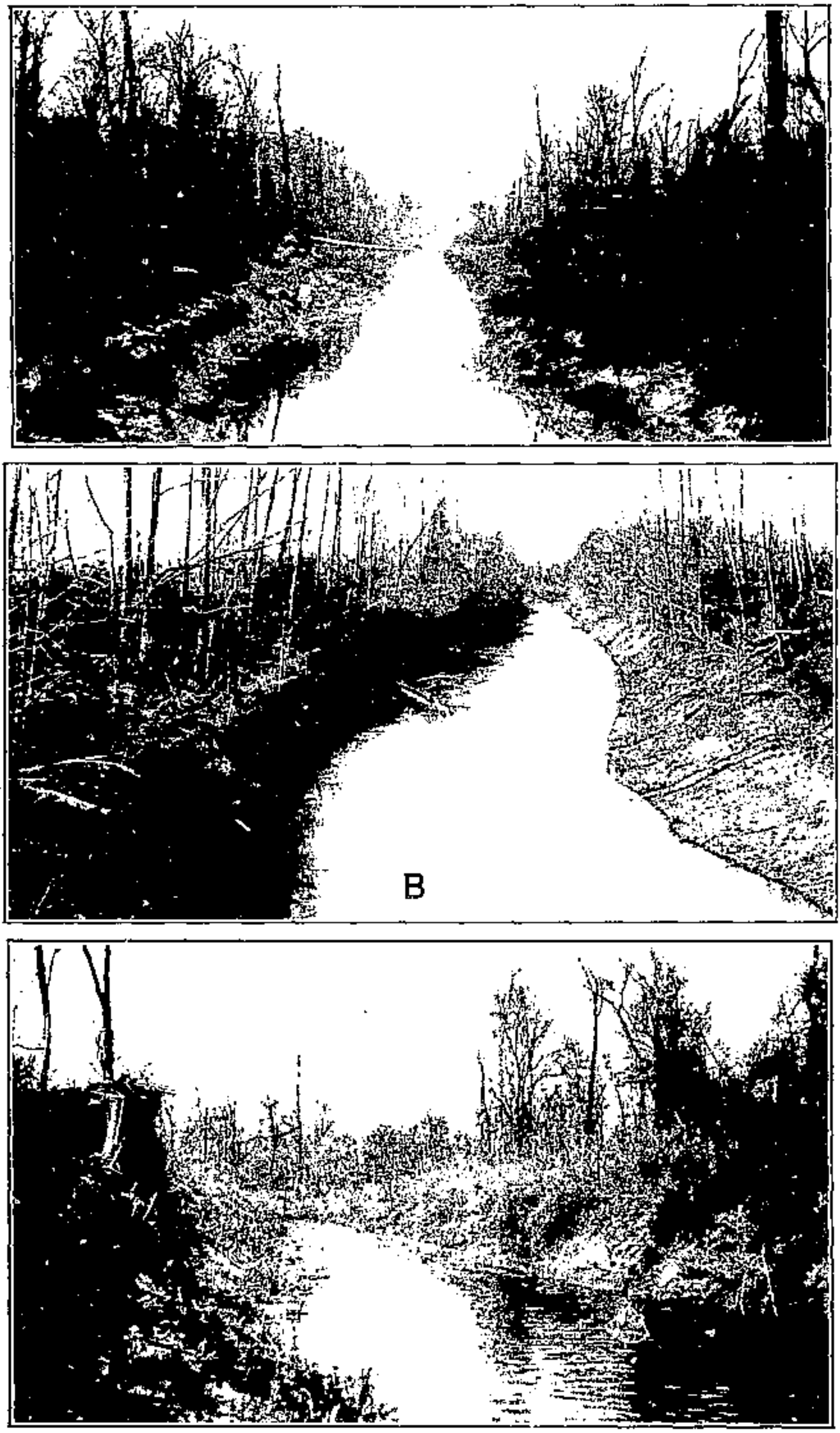


B



C

A, Bogue Phalia dredged channel near Helm, Miss., looking up slope course, 1915; B, Bogue Phalia natural channel near Heads, Miss., looking up slope course, March, 1926; C, Pecan Bayou dredged channel near Shaw, Miss., looking up slope course, 1915. (See Table 2)



A

B

C

A, Bogue Hasty dredged channel near Shaw, Miss., looking up slope course, 1915; B, same location as A above, looking up slope course, March, 1926; C, East Bogue Hasty dredged channel near Shaw, Miss., looking up slope course, 1915. (See Table 2)

The condition of the channel in March, 1926, is shown in Plate 4, B. It is believed that there was less vegetation at high stages on the right bank (left side of view) when the first measurements were made, in 1924. The left-side slope was quite clean, smooth, and regular and the right-side slope was irregular, subject to caving, and partly covered with vegetation, conditions very similar to those existing in 1915. (See fig. 3, D for average cross section.) There was somewhat more variation in cross section than in 1915. (Fig. 4, D.)

Values of *n* obtained for this channel are a little lower than those obtained during 1915, and it is believed that the channel was in better condition at the time of the later experiments as regards the amount of vegetation in the channel. The differences in the values of *n* obtained during the years 1924, 1925, and 1926 are probably due to varying conditions of vegetation during this period.

PECAN BAYOU

A course 665 feet long was used for slope measurements on Pecan Bayou, located about 600 feet above the highway bridge, 5 miles directly south from Skene and about 3 miles from Shaw. The cross section of the channel at this place was quite uniform (fig. 4, E.), and no surface water entered along the course, which was situated between two bends in the channel. A suspension footbridge for gaging purposes was placed near the lower end of the course.

Conditions on Pecan Bayou were similar to those described below for West Bogue Hasty. Much water was impounded along the course during periods of no flow. It appears that material was deposited in the channel below to impound water for the purpose of fishing. The side slopes of the channel were very regular. Some weeds were found in the channel, but not nearly as many as in the channel of East Bogue Hasty. (Pl. 3, C and fig. 3, E.) The soil is a dark-colored clay, which cracks and crumbles when dry. The slope of the water surface was found to be exceedingly small, much less than the grades designated in the original design of the channel. This was due, no doubt, to the amount of sediment deposited in the channel below the course. The values of *n* obtained are shown in Table 2.

WEST BOGUE HASTY

For slope measurements on this channel during 1915, a straight course 757 feet long, of quite uniform cross section at bankful stage (fig. 4, F) was selected, north of the highway bridge about 1 mile east of Litton and about 6 miles from Shaw. At the lower end of the course, stakes for slope measurements were located about 50 feet above the entrance of a lateral surface ditch. The gagings for discharge were made from a suspension footbridge built about in the middle of the course.

The collection of drift by the bridge below the course and sedimentary deposits as a result of the drift and the entrance of a lateral ditch just above the bridge rendered this course rather unsuitable for accurate determinations of the value of *n*. During periods of no flow a pond of stagnant water extended nearly the whole length of the course, this being due to the sediment deposited near the bridge. The side slopes and bed of the channel were quite regular.

Some weeds were found on the side slopes. (Pl. 5, A.) The soil is similar to that found in the channel of Bogue Hasty. (See fig. 3, G for average cross section.) The results of the experiments on this ditch are shown in Table 2.

The slope course used in 1924 to 1926 was straight and 897 feet long, and included the shorter course used during 1915. Gagings were made from the highway bridge 1 mile east of Litton, which had a main span of 29 feet. Conditions for measuring both discharge and slope were now fairly good, the channel having been redredged in 1923. A view of the channel taken in August, 1924, is shown in Plate 5, B. The condition with regard to vegetation was much worse in 1926. There was not much variation in cross section at high stages, but considerable for low stages. (Fig. 4, G.) The side slopes were subject to caving, and were irregular and uneven. (Fig. 3, G.)

Higher values of n were obtained during 1926 than during 1924, partly because there was more vegetation in the channel at the time of the last measurements. A higher value was obtained in May, 1924, than in February of the same year, 0.044 as compared with 0.038, due largely to the foliage on the vegetation in the later month. However, part of these differences are likely due to channel condition being worse for the lower than for the higher stages of flow (see Table 2).

EAST BOGUE HASTY

The course for slope measurements on East Bogue Hasty was established above the highway bridge, about 2 miles east of Litton and about 5 miles from Shaw. A stretch of 502 feet was selected, its upper end being just below a curve in the channel and the lower end just above the bridge and the entrance of a lateral ditch. The discharge measurements were made from a suspension footbridge about midway of the course. This course was rather short for accurate determinations of slope but was the straightest stretch of comparatively uniform section (fig. 4, H) that could be found near the lower end of the channel.

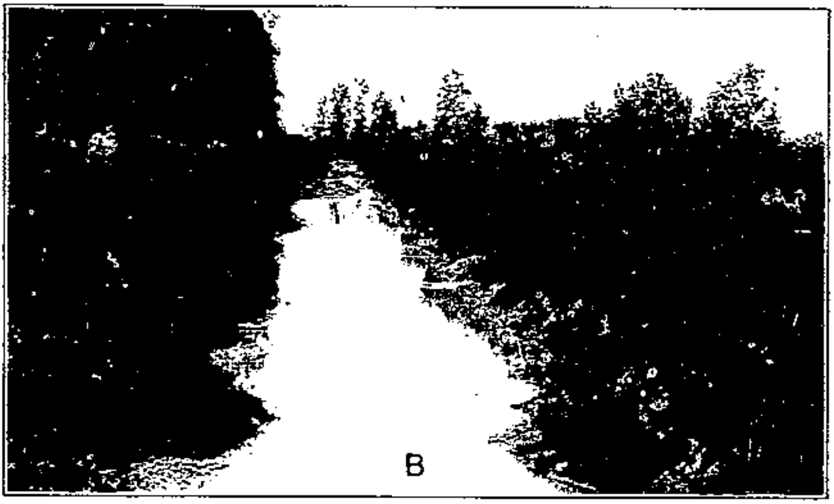
The side slopes, and in some places the bed of the channel, were covered with weeds and weed stubble, and the side slopes were slightly irregular. (Pl. 4, C.) Practically no caving took place along the course, which fact was due, no doubt, to the vegetation covering the banks. The soil is quite similar to that in the channel of Pecan Bayou.

The values obtained for n are shown in Table 2, and, as would be expected from the condition of the channel, are even higher than those found for a bankful stage of Bogue Hasty. Some trouble was experienced during the measurements, owing to drift collected at the bridge, and this may be in part responsible for the rather high values obtained for n. (See fig. 3, H for average cross section.)

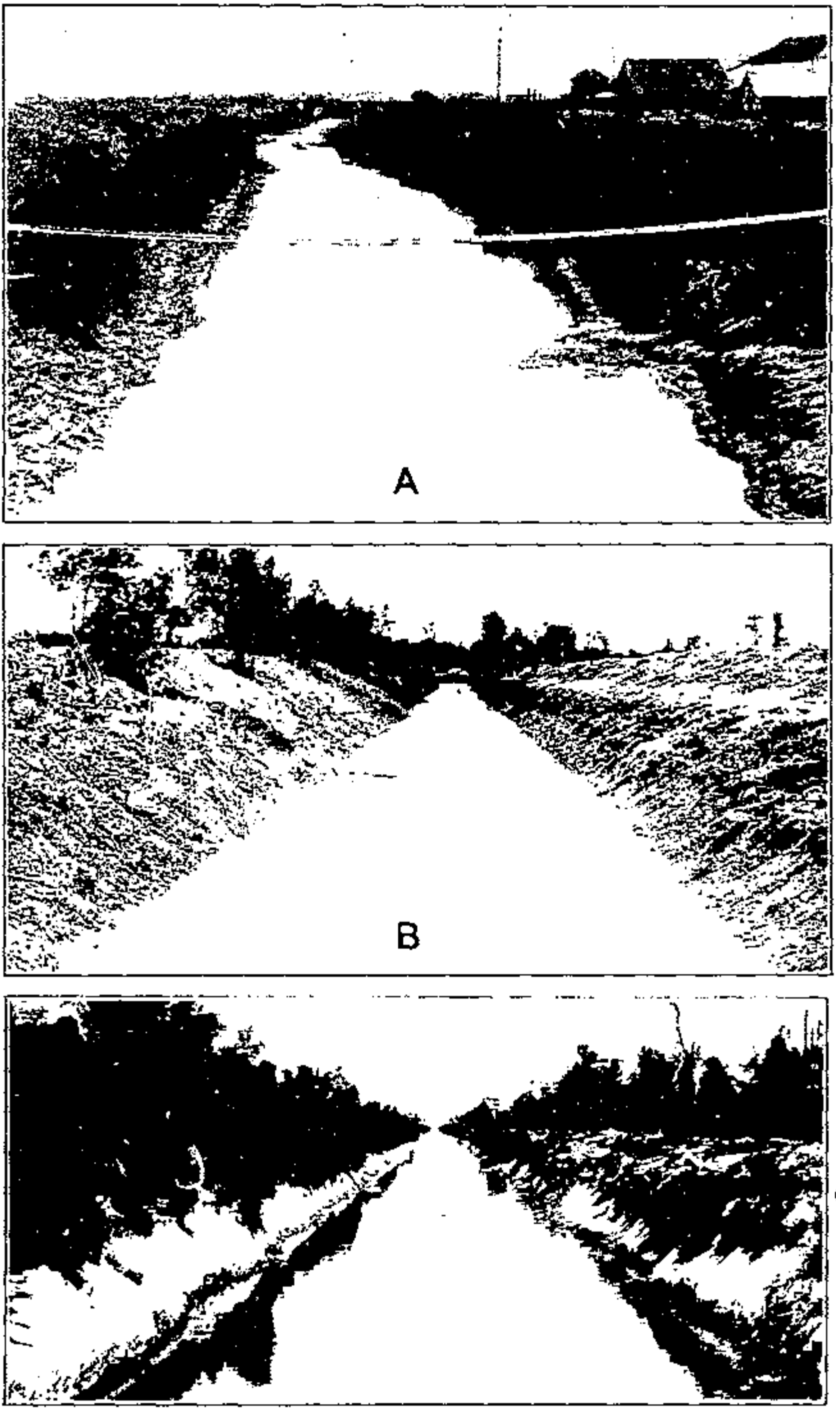
HORSESHOE BAYOU

A straight slope course of 1,020 feet was used on this channel. Accurate discharge measurements were obtained from a specially constructed suspension foot bridge. Conditions for measurements on this channel were very good. The bottom of the channel was rather rough and irregular, and there were two small sand bars where water

A



A, West Bogue Hasty dredged channel near Shaw, Miss., looking up slope course, 1915; B, same location as A above, looking up slope course, August, 1921. C, Horseshoe Bayou dredged channel near Cleveland, Miss., looking down slope course, May, 1924. (See Table 2)



C

A, Dredged ditch No. 1, near Shaw, Miss., looking down slope course, March, 1926 (see Table 2); B, Snake Creek dredged channel near [illegible], Miss., looking up slope course, April, 1924 (see Table 2); C, South Forked Deer River dredged channel near Roberts, Tenn., looking up slope course, 1916 (see Table 3) entered from openings in the banks. No appreciable amount of water entered, however, while gagings were being made. There was a tendency for the cross section to increase somewhat from the upper to the lower end of the slope course. (Fig. 4, I.) A good idea of the condition of the channel with regard to vegetation and side slopes can be obtained from a view taken in August, 1924, and shown in Plate 5, C. (See fig. 3, I for average cross section of channel.)

It will be seen in Table 2 that there is a considerable difference in the values of n obtained for the two nearly similar lower stages. This is due to the fact that there was a much greater amount of weeds and grass in the bottom of the channel in June when the value 0.053 was obtained than in May when the value 0.035 was obtained. It is believed that a value of about 0.030 during the winter months would have been found for this channel, had it not been for the condition of the bottom.

DITCH NO. 1

Discharge measurements on this channel were made from a suspension footbridge, and conditions were very good for accurate measurements. The slope course was straight and 995 feet long. The gaging station was located about 2 miles west of Shaw. The size of the cross section decreased considerably from the upper end to about the middle of the course, and then increased to the end of the course. (Fig. 4, J.) The side slopes were quite irregular and rough, varying from steep to very flat, and were covered with a growth of grass and dead weeds when the measurements were made. The condition is well shown in Plate 6, A. (See fig. 3, J for average cross section.)

Two measurements were made at about half-bankful stage, each giving the value of n as 0.041. It is believed that a value of 0.035 would have been obtained for a bankful stage.

SNAKE CREEK

Conditions for both slope measurements and discharge were good on this channel. The gaging station was located on a single-span bridge at Victor. The slope course was straight and 1,000 feet in length. As may be seen from the view in Plate 6, B, this channel was in excellent condition. The cross-sectional area was quite uniform (fig. 4, K); the side slopes and bottom were regular and even. (See fig. 3, K for average cross section.)

Only one measurement was made, and a value of 0.028 was obtained for n with the depth of flow 8.6 feet. The dredging of this channel was completed only a few weeks before the measurement was made.

DISCUSSION OF WASHINGTON AND BOLIVAR COUNTIES EXPERIMENTS

The results of these experiments show that for a newly dredged channel of regular side slopes and uniform section in this locality the value of n is low, judging from the value 0.028 obtained for Snake Creek. It is apparent, however, that channels in this locality soon deteriorate, principally on account of the growth of vegetation. The larger dredged channels such as Bogue Hasty and the Bogue Phalia at Helm maintain themselves in better condition than the smaller ones, as a general rule, no doubt because of the greater low-water flow, which tends to prevent the rapid growth of vegetation, particularly on the bottom of the channel. Erosion also, in the Bogue Phalia channel near Helm, has tended to prevent the rapid growth of vegetation. In view of the rapid deterioration of these watercourses, it is not believed advisable to use a value of n less than 0.035 in the design of channels in this section or in similar sections of the country, and then the vegetation should be cleared out annually to maintain the hydraulic efficiency.

EXPERIMENTS IN WESTERN TENNESSEE

These experiments were conducted during the years 1916 and 1917. Values of n were obtained for six different courses of the channel of the South Forked Deer River and for courses of the channels of the North Forked Deer River, Huggins Creek, Sugar Creek, and Cypress Creek. The topography of the watersheds of these channels is rolling and somewhat hilly.

SOUTH FORKED DEER RIVER NEAR ROBERTS

Gagings of this channel were made from a single-span highway bridge about 1 mile south of Roberts. The slope course was 1,412 feet long, and was located just above the gaging station. The channel increased gradually in size from the upper to the lower end of the course, there being no abrupt changes in size or shape along the course. (Figs. 5, A and 6, A.) There was no vegetation nor any marked irregularities in the channel. (Pl. 6, C.) Considerable erosion had taken place in this channel to which was largely due, no doubt, the remarkably few irregularities and the freedom from vegetation. As shown in Table 3, lower values of n were obtained for this channel than for any of the other channels in Tennessee.

SOUTH FORKED DEER RIVER NEAR JACKSON

Discharge measurements of this channel were made from a single-span skew highway bridge on the Bolivar levee road about one-half mile from Jackson. The upper end of the slope course was located about 75 feet below the bridge; the course was 952 feet long, and straight. The cross-sectional area was fairly uniform for high stages, but for low stages several abrupt changes in size occurred. (Figs. 5, B and 6, B.) The effect of roughness and irregularities in the lower portion of the channel upon the value of n is revealed in the results obtained. (Table 3.) Although the channel was free from vegetation and obstructions, yet the values of n obtained are considerably higher than those obtained for the channel at Roberts. The irregularities in the channel were left at the time of construction, the bottoms and sides having never been smoothed up properly. (Pl. 7, A.)

TABLE 3.—*Results of experiments made in western Tennessee*

SOUTH FORKED DEER RIVER DREDGED CHANNEL NEAR ROBERTS, TENN.

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
		Feet	*Feet*	*Second-feet*	*Sq. ft.*	*Ft. per sec.*	*Feet*				
1	Feb. 26, 1916	7.7	51.0	614.3	328.4	1.87	5.76	0.000094	80.5	0.026	*Course*, straight; 1,412 feet long. *Cross section*, very little variation in shape, for variation in size, see Fig. 6, A. *Side slopes*, regular and smooth. *Bottom*, even and fairly smooth. *Soil*, lower part, hard clay; upper part, clay loam. *Condition*, no vegetation or obstructions of any sort in channel. *Constructed*, October, 1915. (Pl. 6, C and fig. 5, A.)
2	Feb. 10, 1916	8.9	52.4	798.2	390.0	2.04	6.50	.000094	82.6	.025	
3	Mar. 29, 1916	9.5	53.4	919.4	421.8	2.18	6.84	.000096	85.2	.025	
4	Apr. 4, 1916	10.3	54.5	1,252.1	465.0	2.70	7.28	.000124	90.0	.024	
5	Mar. 4, 1916	10.8	55.2	1,502.6	494.0	3.04	7.55	.000166	86.0	.025	
	----------	[1] 13.0	----------	----------	----------	----------	----------	----------	----------	----------	

SOUTH FORKED DEER RIVER DREDGED CHANNEL AT BOLIVAR ROAD NEAR JACKSON, TENN.

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
6	Dec. 13, 1916	4.3	37.6	191.6	115.9	1.66	2.89	0.000530	42.4	0.042	*Course*, straight; 952 feet long. *Cross section*, very little variation in shape; for variation in size, see Fig. 6, B. *Side slopes*, fairly regular near top, but extremely irregular and uneven near bottom. *Bottom*, very uneven and full of holes. *Soil*, heavy clay loam. *Condition*, no vegetation or obstructions in channel. *Constructed*, March, 1916. *General remarks*, high values of n are due to very rough and irregular condition of channel as originally dredged. The upper portion of channel is fairly regular. (Pl. 7, A and fig. 5, B.)
7	Dec. 20, 1916	4.95	38.4	282.2	143.0	1.97	3.33	.000555	45.8	.040	
8	Dec. 22, 1916	5.0	38.5	290.4	147.0	1.98	3.40	.000562	45.3	.040	
9	Mar. 31, 1917	5.1	38.0	375.0	150.0	2.50	3.46	.000694	51.2	.036	
10	Feb. 21, 1917	5.5	39.2	433.0	166.0	2.61	3.69	.000630	54.2	.035	
11	Jan. 17, 1917	5.8	39.6	477.0	178.0	2.68	3.87	.000642	53.8	.035	
12	Dec. 28, 1916	9.3	51.6	1,078.0	344.0	3.13	5.69	.000477	60.2	.034	
13	Jan. 31, 1917	9.8	54.0	1,296.0	366.0	3.55	5.83	.000534	63.6	.032	
14	Jan. 6, 1917	10.4	57.1	1,362.0	399.4	3.41	6.10	.000436	66.1	.031	
	----------	[1] 11.0	----------	----------	----------	----------	----------	----------	----------	----------	

SOUTH FORKED DEER RIVER DREDGED CHANNEL NEAR HENDERSON, TENN., 1916

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
15	Mar. 30, 1916	3.2	26.1	115.2	73.3	1.57	2.46	0.000257	62.4	0.028	*Course*, straight; 624 feet long. *Cross section*, very little variation in shape; for variation in size, see Fig. 6, C. *Side slopes*, slightly irregular. *Bottom*, fairly regular; uneven in places with small depressions. *Soil*, heavy clay near bottom; clay loam near top. *Condition*, practically no vegetation in channel. *Constructed*, November, 1914. (Pl. 7, B and fig. 5, C.)
16	Mar. 1, 1916	3.8	27.1	169.4	89.0	1.90	2.81	.000303	57.2	.031	
17	May 16, 1916	3.9	27.4	193.2	91.5	2.11	2.87	.000305	71.3	.025	
18	May 22, 1916	5.8	30.4	358.0	147.0	2.43	3.96	.000361	64.4	.029	
19	May 3, 1916	6.4	31.5	434.6	168.3	2.58	4.34	.000345	66.8	.029	
	----------	[1] 9.3	----------	----------	----------	----------	----------	----------	----------	----------	

[1] Average maximum depth at bankful stage.

TABLE 3.—*Results of experiments made in western Tennessee*—Continued

SOUTH FORKED DEER RIVER DREDGED CHANNEL NEAR HENDERSON, TENN., 1917

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
		Feet	*Feet*	*Second-feet*	*Sq. ft.*	*Ft. per sec.*	*Feet*				
20	Feb. 23, 1917	4.1	29.5	224.[illegible]	100.0	2.24	3.11	0.000532	55.0	0.033	*Course*, same as above. *Cross section*, very little variation in shape; for variation in size, see Figure 6, D. *Condition*, channel in practically the same condition as described above, but slightly enlarged due to caving and erosion.
21	Jan. 4, 1917	4.2	29.6	240.8	103.0	2.34	3.17	.000486	59.6	.030	
22	Jan. 20, 1917	4.3	29.7	260.9	106.0	2.46	3.24	.000435	65.6	.028	
23	Jan. 23, 1917	5.3	31.3	333.9	138.0	2.42	3.80	.000314	69.2	.027	
24	Feb. 15, 1917	6.1	32.7	423.0	164.0	2.58	4.34	.000313	70.0	.028	
25	Jan. 6, 1917	[1] 9.3	36.6	953.1	278.9	3.44	6.04	.000332	76.8	.027	

NORTH FORKED DEER RIVER DREDGED CHANNEL NEAR TRENTON, TENN., 1916

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
26	Feb. 4, 1916	3.0	26.5	37.6	49.2	0.76	1.03	0.000166	53.2	0.030	*Course*, straight; 690 feet long. *Cross section*, very little variation in shape; for variation in size, see Figure 6, E. *Side slopes*, fairly regular, smooth, and steep. *Bottom*, rather irregular. *Soil*, clay loam. *Condition*, no vegetation or obstructions, banks caving badly. *Constructed*, May, 1915. (Pl. 7, [illegible])
27	May 4, 1916	3.8	27.3	50.4	55.0	1.08	2.08	.000126	66.8	.024	
28	May 15, 1916	10.7	40.3	1,167.0	316.0	3.69	6.22	.000382	75.6	.027	
	----------	[1] 11.0	----------	----------	----------	----------	----------	----------	----------	----------	

NORTH FORKED DEER RIVER DREDGED CHANNEL NEAR TRENTON, TENN., 1917

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
29	July 22, 1917	2.5	28.8	76.1	50.0	1.52	1.64	0.000332	65.2	0.024	*Course*, same as above. *Cross section*, very little variation in shape; for variations in size, see Figure 6, F. *Condition*, very similar to that described above except that the size has increased greatly due to erosion and caving of banks. (See fig. 5, F for cross section.)
30	Apr. 9, 1917	3.1	30.5	125.8	69.2	1.82	2.12	.000361	65.7	.025	
31	July 24, 1917	3.4	31.8	189.3	81.0	2.34	2.38	.000450	71.6	.024	
32	----do----	3.9	33.4	246.0	97.0	2.54	2.70	.000432	74.2	.024	
33	----do----	4.9	36.8	381.8	134.0	2.85	3.34	.000427	75.6	.024	
34	July 23, 1917	8.9	47.8	1,257.5	305.0	4.12	5.54	.000468	81.0	.025	
35	----do----	9.1	48.0	1,317.0	313.0	4.21	5.64	.000507	78.8	.026	
36	----do----	9.2	48.2	1,324.0	318.0	4.16	5.70	.000520	76.4	.026	
37	Jan. 5, 1917	10.5	48.8	1,513.0	367.3	4.12	6.30	.000444	77.3	.027	
	----------	[1] 11.0	----------	----------	----------	----------	----------	----------	----------	----------	

HUGGINS CREEK DREDGED CHANNEL NEAR FINGER, TENN., 1916

38	May 22, 1916	1.8	18.1	50.7	32.7	1.55	1.56	0.000855	42.5	0.035	*Course*, straight; 914 feet long. *Cross section*, rather abrupt variations in shape; for variation in size, see fig. 6, G. *Side slopes*, very irregular. *Bottom*, rather smooth and even. *Soil*, clay loam containing some sand. *Condition*, growth of grass, weeds, and small sprouts in channel; considerable caving of banks. *Constructed* Oct., 1914. (Fig. 5, G.)
39	Feb. 9, 1916	1.85	18.3	54.1	34.0	1.60	1.62	.000923	41.4	.037	
40	Apr. 3, 1916	2.0	19.0	63.3	36.6	1.73	1.71	.000824	46.2	.034	
41	Feb. 1, 1916	3.0	21.0	97.4	51.0	1.91	2.16	.000875	43.9	.037	
42	May 30, 1916	4.0	23.0	159.5	74.2	2.15	2.75	.000564	54.5	.032	
43	do	[1]6.3	31.0	371.8	140.4	2.65	3.64	.000620	55.8	.033	

HUGGINS CREEK DREDGED CHANNEL NEAR FINGER, TENN., 1916–17

44	Dec. 8, 1916	2.0	18.9	49.1	35.4	1.39	1.72	0.000738	38.9	0.040	*Course*, straight; 618 feet long; part of 1916 course. *Condition*, channel in considerably worse condition than when first series of measurements were made; more irregular and rough due to caving banks and a great deal more vegetation in channel. (Pl. 8, A and fig. 6, H.)
45	do	2.3	19.6	63.2	40.5	1.56	1.87	.000713	42.6	.037	
46	Dec. 28, 1916	2.55	20.1	88.2	46.0	1.92	2.06	.000888	44.8	.037	
47	Feb. 15, 1917	2.60	20.2	88.4	47.0	1.88	2.09	.000834	45.1	.036	
48	Dec. 28, 1916	3.0	20.8	115.2	55.9	2.06	2.34	.000835	46.6	.036	
49	Jan. 18, 1917	3.2	21.1	123.6	58.8	2.10	2.42	.000832	46.9	.036	
50	Mar. 3, 1917	3.5	22.2	143.6	64.3	2.23	2.55	.000877	47.2	.036	
	----------	[1]6.3	------	------	------	------	------	------	------	------	

SUGAR CREEK DREDGED CHANNEL NEAR HENDERSON, TENN.

51	Mar. 29, 1917	1.9	17.3	23.1	25.4	0.91	1.37	0.000729	28.8	0.050	*Course*, 669 feet long; first half straight, last half curved. *Cross section*, very little variation in shape; for variations in size, see fig. 6, I. *Slide slopes*, upper part, smooth and regular; lower part, rather rough. *Bottom*, very rough and irregular with numerous holes. *Soil*, stiff clay loam; does not wash easily. *Condition*, some roots extending from sides of channel; very little vegetation in channel. *Constructed*, Dec., 1915. *Remarks*, very rough condition of bottom is mainly responsible for high values of *n* obtained. (Pl. 8, B and fig. 5, I.)
52	Mar. 27, 1917	2.1	17.5	29.8	29.2	1.02	1.53	.000825	28.8	.050	
53	Jan. 4, 1917	2.6	18.2	63.6	39.9	1.59	1.96	.000970	36.5	.044	
54	Feb. 15, 1917	3.5	19.4	148.0	57.8	2.56	2.57	.001232	45.5	.038	
55	Dec. 28, 1917	6.3	27.2	322.0	116.0	2.78	3.41	.000936	40.2	.037	
56	Jan. 29, 1917	6.4	27.4	376.2	117.5	3.20	3.42	.001111	51.8	.036	
57	Jan. 22, 1917	6.6	28.2	355.2	121.9	2.92	3.44	.000920	51.9	.036	
58	July 26, 1917	6.9	29.2	347.2	128.0	2.71	3.49	.000738	53.5	.034	
59	Jan. 5, 1917	[1]7.1	29.9	406.5	132.2	3.08	3.51	.000855	56.1	.033	

CYPRESS CREEK DREDGED CHANNEL NEAR BETHEL SPRINGS, TENN.

60	Feb. 15, 1917	0.7	12.5	7.9	8.9	0.89	0.67	0.002080	23.9	0.047	*Course*, straight; 308 feet long. *Cross section*, abrupt variations in shape; for variation in size, see fig. 6, J. *Side slopes*, very irregular and rough. *Bottom*, uneven; subject to variation due to sand deposits. *Soil*, clay loam. *Condition*, exposed perimeter above low water practically covered with grass and weeds. *Constructed*, December, 1915. (Pl. 9, A and fig. 5, J.)
61	July 23, 1917	2.3	17.3	72.4	33.8	2.14	1.76	.002435	32.7	.047	
62	do	2.9	18.8	103.7	42.1	2.46	1.99	.001915	39.9	.040	
	----------	[1]5.5	------	------	------	------	------	------	------	------	

[1] Average maximum depth at bankful stage.

TABLE 3.—*Results of experiments made in western Tennessee*—Continued

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
	SOUTH FORKED DEER RIVER AT CAMPBELLS LEVEE ROAD, NEAR JACKSON, TENN., IRREGULAR DREDGED CHANNEL										
		Feet	*Feet*	*Second-feet*	*Sq. ft.*	*Ft. per sec.*	*Feet*				
63	Mar. 20, 1916	4.5	43.6	395.2	176.1	2.24	3.61	0.000571	49.4	0.038	*Course*, fairly straight; 534 feet long. *Cross section*, rather gradual variations in shape; for variation in size, see fig. 6, K. *Side-slopes*, very irregular. *Bottom*, very rough and uneven. *Soil*, sandy clay loam. *Condition*, very little vegetation; few obstructions in channel. *Constructed*, August, 1914. (Pl. 9, B and fig. 5, K.)
64	Feb. 25, 1916	6.1	46.9	545.9	249.0	2.19	4.65	.000552	43.2	.046	
65	Mar. 29, 1916	7.3	49.8	735.7	305.0	2.41	5.33	.000452	49.2	.041	
66	Mar. 4, 1916	7.5	50.3	715.1	315.6	2.27	5.45	.000300	56.2	.037	
		[1] 13.0									
	SOUTH FORKED DEER RIVER AT CAMPBELLS LEVEE ROAD, NEAR JACKSON, TENN., OLD STRAIGHT RIVER CHANNEL										
67	Mar. 20, 1916	7.0	40.0	395.2	196.2	2.01	4.44	0.000584	39.5	0.050	*Course*, fairly straight; 497 feet long. *Cross section*, considerable variation in shape; for variation in size, see fig. 6, L. *Side slopes*, irregular. *Bottom*, irregular with deep holes. *Soil*, sandy clay loam. *Condition*, sides of channel covered with trees, roots, and vines and subject to caving; logs, branches, and other drift on bottom of channel. (Pl. 10, A and fig. 5, L.)
68	Feb. 25, 1916	8.0	41.7	545.9	240.2	2.27	5.00	.000734	37.2	.055	
69	Mar. 29, 1916	8.8	43.2	735.7	275.0	2.68	5.50	.001088	34.4	.062	
70	Mar. 4, 1916	8.9	43.7	715.1	281.9	2.54	5.66	.000952	34.6	.062	
71	Feb. 3, 1916	11.5	48.8	1,066.6	403.2	2.64	7.19	.000501	44.1	.050	
		[1] 13.5									
	SOUTH FORKED DEER RIVER AT CAMPBELLS LEVEE ROAD, NEAR JACKSON, TENN., OLD CROOKED RIVER CHANNEL										
72	Mar. 20, 1916	5.1	46.5	395.2	241.2	1.64	4.15	0.003773	13.1	0.152	*Course*, very crooked, containing four distinct curves; 705 feet long at low water. *Cross section*, large variations in shape; for variation in size, see fig. 6, M. *Side slopes*, very irregular. *Bottom*, very irregular and full of holes. *Soil*, sandy clay loam. *Condition*, many roots, trees, and bushes on sides, and many logs, large trees, and other drift on bottom; trees are continually falling into channel, due to caving banks. (Pl. 10, B and fig. 5, M.)
73	Feb. 25, 1916	6.5	50.0	545.9	311.5	1.75	4.99	.003812	12.7	.162	
74	Mar. 29, 1916	7.6	54.0	735.7	366.0	2.01	5.56	.003450	14.6	.150	
75	Mar. 4, 1916	7.8	55.0	715.1	376.7	1.90	5.68	.002700	15.3	.146	
76	Feb. 3, 1916	11.1	64.5	1,066.6	575.8	1.85	7.60	.001486	17.4	.140	
		[1] 13.0									

[1] Average maximum depth at bank-full stage.

x

A, South Forked Deer River dredged channel at Bolivar Levee Road near Jackson, Tenn., looking down slope course, 1917. B, South Forked Deer River dredged channel near Henderson, Tenn., looking up slope course, 1916. C, North Forked Deer River dredged channel near Trenton, Tenn., looking down slope course, 1916. (See Table 5.)

SOUTH FORKED DEER RIVER NEAR HENDERSON

The gaging station was located on the single-span highway bridge about 1½ miles east of Henderson, Tenn. A straight course 624 feet in length, below the gaging station, was selected for slope measurements. Experiments were made on this channel during both 1916 and 1917, and there was very little difference in the channel for the two sets of experiments or in the values of n obtained for the corresponding stages. (Table 3.) It is believed that the results obtained are quite accurate. The channel as a whole was in very good condition. The side slopes were slightly irregular, the bottom was fairly even except for a few depressions, and there was practically no vegetation in the channel. (Pl. 7, B; and figs. 5, C; 6, C; and 6, D.)

NORTH FORKED DEER RIVER

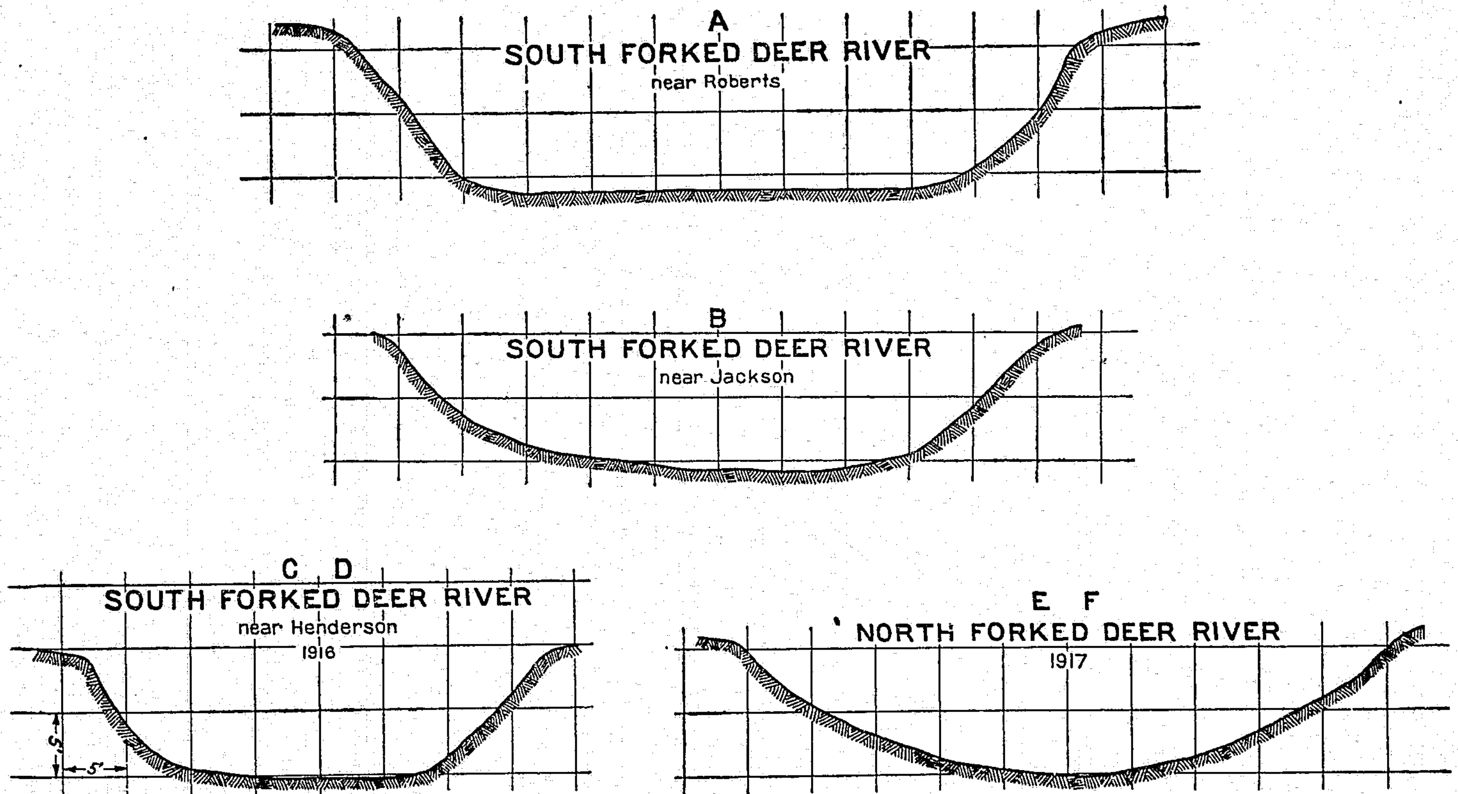
A single-span skew bridge on the Huntingdon levee road about one-half mile from Trenton was used as a gaging station. The slope course was straight and extended upstream from near the bridge for a distance of 699 feet. The variations in the cross-sectional area were quite large, but there were no abrupt changes in section for the higher stages. Owing to the fact that the size of the channel increased gradually from the upper to the lower end of the course, it is not believed that the differences in the area of the cross section had any appreciable effect upon the value of n for the course. (Figs. 5, E; 6, E; and 6, F.) There were practically no vegetation or other obstructions in the channel. (Pl. 7, C.)

Referring to measurements 28 and 37 in Table 3, it is seen that the values of n obtained for the highest stages during 1916 and 1917 were the same, 0.027. The increase in size of the channel due to erosion during the interval of time between the above measurements was 23.5 per cent, from which it is seen that the erosion of the channel in this particular instance produced no appreciable change in the value of n for the channel. The low values of n for the higher stages as compared with the results obtained for the other channels may be attributed to the absence of abrupt changes in cross section and to the freedom from growth and obstructions in the channel.

HUGGINS CREEK

The Huggins Creek gaging station was located on the single-span highway bridge about 100 yards east of the Mobile & Ohio Railroad, near Finger, Tenn. The slope course was straight, extended downstream from the gaging station, and was 914 feet long for the first series of experiments and 686 feet long for the second. (Pl. 8, A; and figs. 5, G; 6, G; and 6, H.)

The values obtained at Finger (Table 3, measurements 38 to 50) are fairly consistent for all stages and are rather high. This is due to the fact that irregularities and growth in the channel are quite evenly distributed from top to bottom of the channel and to large variations in cross section. This channel is rapidly deteriorating, because of caving of the banks and growth in the channel, which fact is indicated by the higher values of n obtained during the second period of investigations.


A
SOUTH FORKED DEER RIVER
near Roberts
B
SOUTH FORKED DEER RIVER
near Jackson
C D
SOUTH FORKED DEER RIVER
near Henderson
1916
5'
5'
E F
NORTH FORKED DEER RIVER
1917

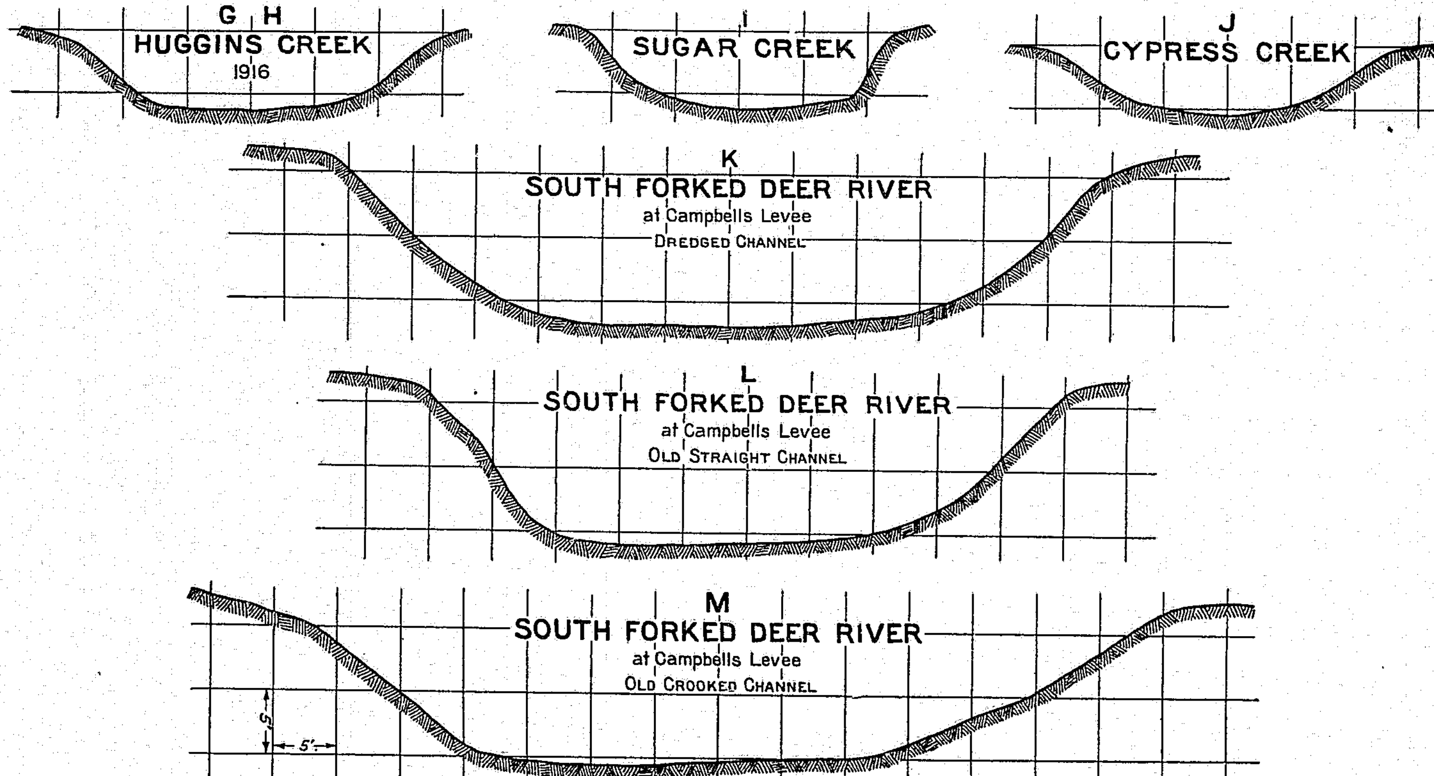


FIGURE 5b.—Average cross sections of channels for experiments in western Tennessee

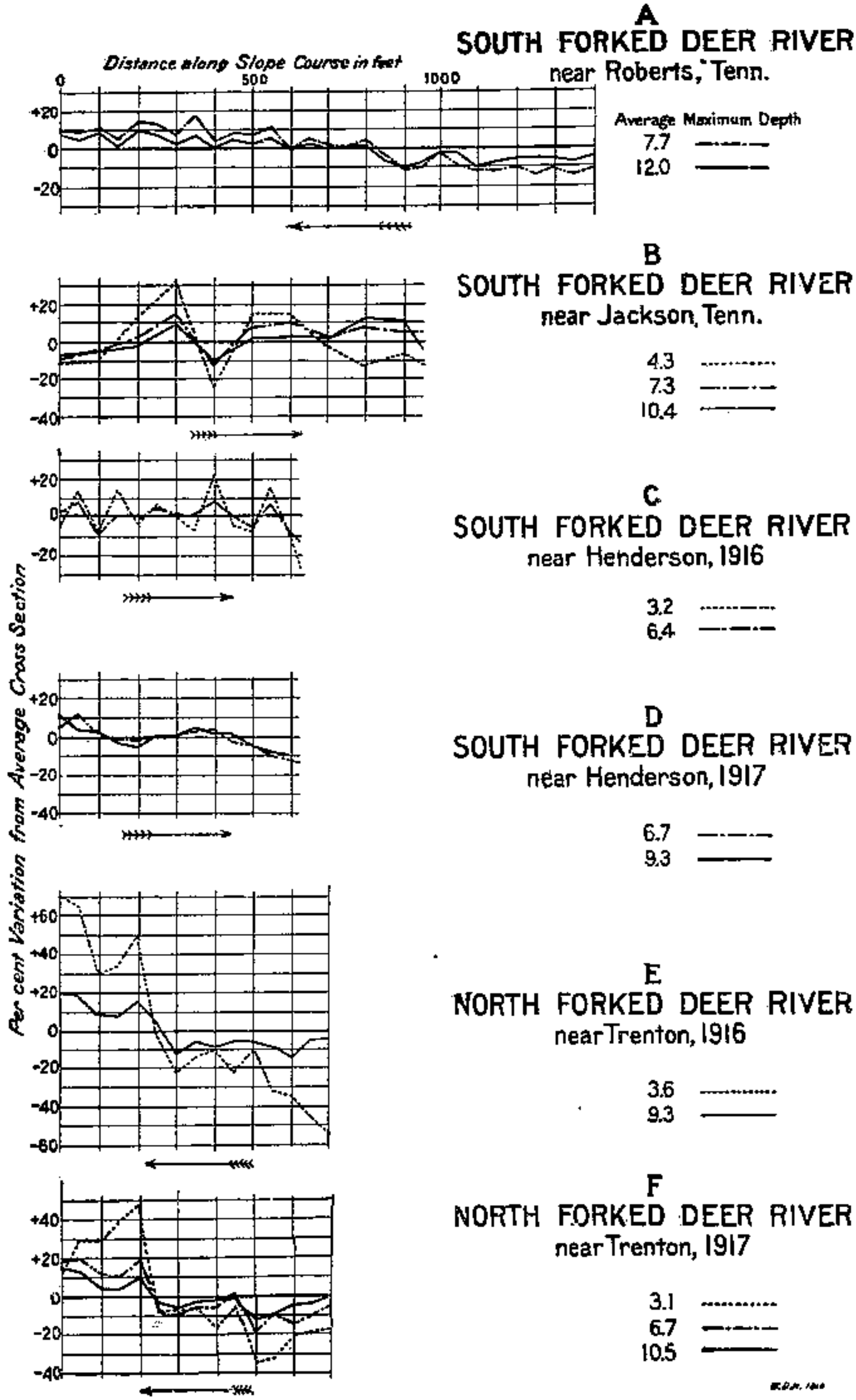
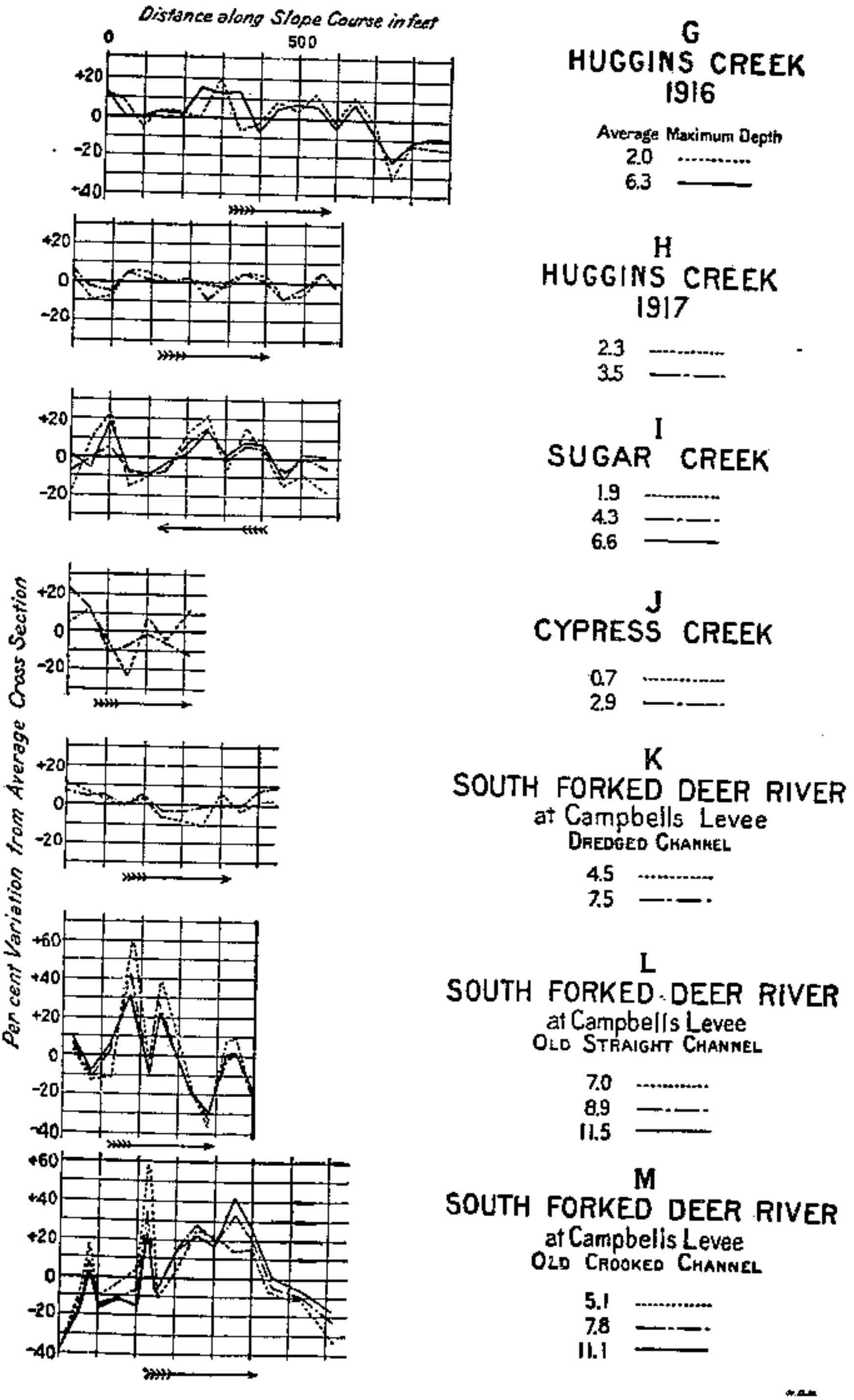


FIGURE 6.—Graphs for experiments in western Tennessee, showing per cent



variation from average cross-sectional area for all cross sections along slope courses

SUGAR CREEK

The gaging station for Sugar Creek was located on a single-span highway bridge a short distance above the Mobile & Ohio Railroad, and about one-half mile from Henderson. The slope course was located below the bridge and was 669 feet long, the first half of the course being straight and the last half a smooth, easy curve. There was found to be no appreciable difference in the slope as between the curved and straight portions of the slope course. Abrupt changes in the size of the channel occurred along the slope course (figs. 5, I and 6, I), and the lower portion of the channel was rough and irregular, not having been finished up properly at the time of construction. (See Table 3 for values of n, and Plate 8, B, for view of channel.)

CYPRESS CREEK

Gagings of Cypress Creek were made from the single-span cattle bridge about 200 yards above the highway bridge at Bethel Springs, Tenn. This bridge was located on the slope course, close to the lower end. The slope course was straight and 308 feet in length.

Values of n for the high stages were not obtained for Cypress Creek. The values obtained (see Table 3, measurements 60 to 62)

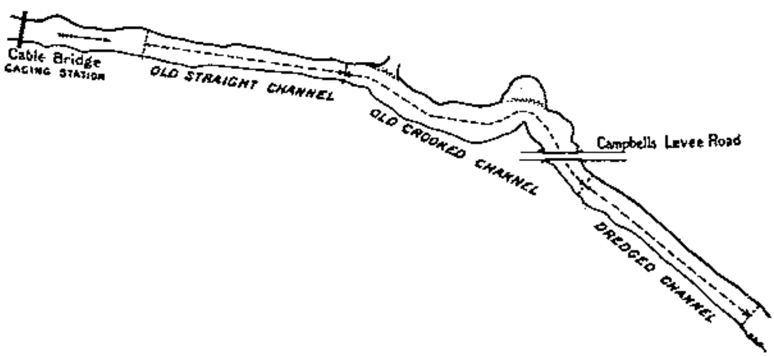


FIGURE 7.—Slope courses of South Forked Deer River at Campbells levee road, near Jackson, Tenn.

are high, as is the case on most of the channels at low stages, and are due to irregularities and vegetation in the channel. It is likely that a lower value of n would have been obtained for a bankful stage. (Pl. 9, A and figs. 5, J and 6, J.)

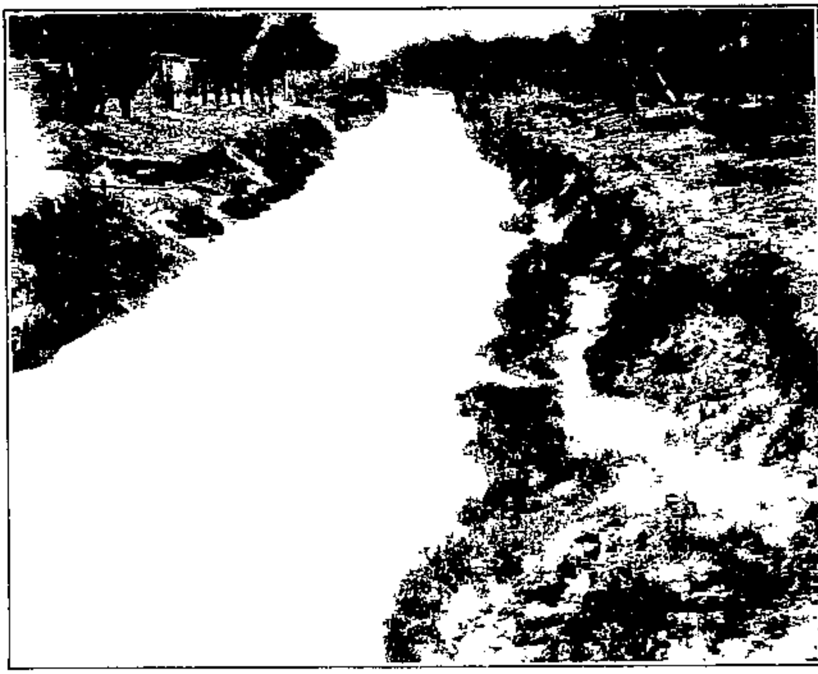
SOUTH FORKED DEER RIVER AT CAMPBELL'S LEVEE ROAD

Experiments were conducted on the river channel at the Campbell's levee road, near Jackson, to determine the values of n for three different but consecutive courses, viz: Old channel (straight and crooked) and new, irregular, dredged channel. The relation of these courses as to location and alignment is shown in Figure 7. A good comparison for the courses can be made, since the values of n for the different courses were computed from the same discharge measurements, made from a suspension footbridge at the upper end of the old straight course, so that any error in discharge would not materially affect the relative values of n. The results obtained, and a detailed description of the three different courses, are given in Table 3, measurements 63 to 76. (See pl. 9, B, and pl. 10, for views of

A

B

A, Huggins Creek dredged channel near Finger, Tenn., looking up slope course, 1917. B, Sugar Creek dredged channel near Henderson, Tenn., looking up slope course, 1917. (See Table 3.)



A

B

A, Cypress Creek dredged channel near Bethel Springs, Tenn., looking up slope course, 1917; B, South Forked Deer River dredged channel at Campbells Levee near Jackson, Tenn., looking down slope course, 1916. (See Table 3)

A

B

A, South Forked Deer River old straight channel at Campbells Levee near Jackson, Tenn., looking down slope course, 1916; B, South Forked Deer River old crooked channel at Campbells Levee near Jackson, Tenn., looking down slope course, 1916. (See Table 3) the three courses.) The conditions found in the two sections of the old channel are typical of those prevailing in channels in this section of the country. The dredged channel is more irregular in shape of cross section than is the usual dredged channel in this part of the country. (For cross sections and variation in size of channel along slope courses see figs. 5, K; 5, L; 5, M; 6, K; 6, L; and 6, M.)

In comparing the values of n obtained for the fourth measurement in each channel (Table 3, measurements 66, 70, and 75) it is seen that the values are 0.037, 0.062, and 0.146 for the dredged, old straight, and old crooked channels, respectively; also that the slopes required for the same discharge are more than three times as much for the old straight channel as for the dredged channel, and about nine times as much for the old crooked channel. In order to show the relative capacities for these three courses of channel, for the values of n given above, the following computations were made in which the slope, hydraulic radius, and cross-sectional area for measurement 66 were used.

[Cross-sectional area = 315.6 square feet. Hydraulic radius = 5.45 feet. Slope = 0.0003]

Channel	n	C	Mean velocity	Discharge	Relative discharges
			Ft. per sec.	*Sec. feet*	*Per cent*
Dredged	0.037	55.3	2.24	707	100.0
Old straight	.062	34.1	1.38	436	61.7
Old crooked	.146	15.1	.61	193	27.3

Results of the above computations show that for similar cross sections and slope the dredged, old straight, and old crooked channels would carry 707, 436, and 193 second-feet respectively, the capacity of the old straight channel being only 62 per cent of that of the dredged, and of the old crooked channel only 27 per cent of the dredged. The difference in the capacities of the old straight channel and old crooked channel is not due entirely to the curves in the latter, since the accumulation of drift, trees, and logs was greater in the crooked channel. However, the difference in the condition of the two channels may be directly attributed to the presence of the curves, since there is a greater tendency for drift and other obstructions to accumulate in a crooked than in a straight course of channel.

DISCUSSION OF WESTERN TENNESSEE EXPERIMENTS

The experiments in western Tennessee cover a greater variety of conditions in channels than do any of the other eight sets, the values of n obtained ranging from 0.024 for the dredged channels near Roberts and Trenton to 0.162 for the old crooked river channel near Jackson. The results, however, do not justify the use of a coefficient as low as the first named above in the design of dredged channels, since it is not the rule that a dredged channel maintains its original efficiency.

TABLE 4.—*Results of experiments made in western Iowa*

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
		ALLEN CREEK DREDGED CHANNEL NEAR MISSOURI VALLEY, IOWA									
		Feet	*Feet*	*Second-feet*	*Sq. ft.*	*Ft. per sec.*	*Feet*				
1	June 4, 1917	7.1	42.3	930.8	196.2	4.74	4.30	0.0002897	134.5	0.014	*Course*, straight; 794 feet long. *Cross section*, practically no variation in shape; for variation in size, see fig. 9, A. *Side slopes*, smooth and regular. *Bottom*, even and regular. *Soil*, heavy, dark, silty loam. *Condition*, practically no vegetation in channel; bottom covered with ½ to 1 foot of mud; sides covered with silt of slimy and slippery nature which was no doubt principally responsible for low value of *n*. *Constructed*, summer of 1916. (Pl. 11, A and fig. 8, A.)
2	do	7.15	42.4	837.1	197.4	4.24	4.32	.0002302	132.7	.014	
		[1] 8.00									
		WILLOW CREEK DREDGED CHANNEL NEAR MISSOURI VALLEY, IOWA									
3	June 4, 1917	6.3	45.5	897.6	216.1	4.15	4.46	0.0002023	138.3	0.014	*Course*, straight; 1,004 feet long. *Cross section*, practically no variation in shape; for variation in size, see fig. 9, B. *Side slopes*, left side slope smooth and even; other side somewhat uneven and irregular. *Bottom*, even and regular. *Soil*, heavy, dark, silty loam. *Condition*, very little vegetation in channel; presence of silt and mud practically the same as described for Allen Creek. *Constructed*, summer of 1916. (Pl. 11, B and Fig. 8, B.)
4	June 6, 1917	6.4	46.0	813.6	220.3	3.69	4.49	.0001694	133.7	.014	
5	June 4, 1917	7.4	48.5	1,195.0	273.5	4.37	5.17	.0001624	150.7	.013	
		[1] 9.0									
		BOYER RIVER DREDGED CHANNEL NEAR MISSOURI VALLEY, IOWA									
6	June 8, 1917	5.3	64.0	904.5	288.0	3.14	4.29	0.0003340	83.1	0.023	*Course*, straight; 868 feet long. *Cross section*, considerable but gradual variations in shape; for variation in size, see fig. 9, C. *Side slopes*, fairly regular. *Bottom*, somewhat uneven and irregular. *Soil*, upper part, dark silty loam; lower part, hard yellow clay. *Condition*, practically no vegetation in channel; bottom and sides coated with layer of slippery silt. *Constructed*, 1910. (Pl. 11, C and Fig. 8, C.)
7	June 7, 1917	7.0	69.0	1,438.6	410.9	3.50	5.58	.0002525	93.3	.021	
8	June 6, 1917	10.5	76.0	2,707.4	663.7	4.08	7.80	.0001883	106.5	.020	
9	June 4, 1917	11.7	79.0	3,213.4	755.5	4.25	8.59	.0001278	128.3	.016	
10	do	12.2	80.0	3,756.0	799.0	4.70	8.99	.0001255	130.9	.015	
		[1] 15.0									
		PIGEON CREEK DREDGED CHANNEL NEAR CRESCENT, IOWA									
11	June 6, 1917	11.7	48.5	1,685.1	329.8	5.11	6.18	0.000642	81.1	0.025	*Course*, straight; 858 feet long. *Cross section*, slight variation in shape; for variation in size, see fig. 9, D. *Side slopes*, left side fairly regular; right side rough and irregular. *Bottom*, slightly irregular. *Soil*, heavy, dark, silty loam. *Condition*, very little vegetation in channel. bottom covered with ½ to 1 foot of mud; sides coated with slippery silt. *Constructed*, 1907. (Pl. 12, A and Fig. 8. D.)
		[1] 12.0									
12	June 6, 1917	12.4	53.8	2,047.1	363.7	5.63	6.12	.000621	91.4	.022	

MONONA-HARRISON DREDGED CHANNEL NEAR ONAWA, IOWA, 1916

13	June 2, 1916	4.4	37.2	221.0	131.3	1.68	2.60	0.000267	63.0	0.027	*Course*, straight; 948 feet long. *Cross section*, slight variations in shape, abrupt variations in size. *Side slopes*, quite irregular, particularly upper part. *Bottom*, fairly regular. *Soil*, dark silty loam. *Condition*, considerable growth in upper portion of channel, none in lower; silty material deposited on bed and sides of channel. *Constructed*, 1910. (Pl. 13, A and fig. 8, E.
14	May 22, 1916	6.9	47.2	614.0	270.8	2.27	4.10	.000261	68.6	.028	
	----------	[1] 10.0	----------	----------	----------	----------	----------	----------	----------	----------	

MONONA-HARRISON DREDGED CHANNEL NEAR ONAWA, IOWA, 1917

15	June 8, 1917	8.5	59.8	499.0	308.0	1.62	4.82	0.000178	55.3	0.036	Practically no change in channel since measurements were made in 1916.
16	June 9, 1917	8.8	61.5	546.5	322.1	1.70	4.92	.0001475	63.2	.032	
	----------	[1] 10.0	----------	----------	----------	----------	----------	----------	----------	----------	

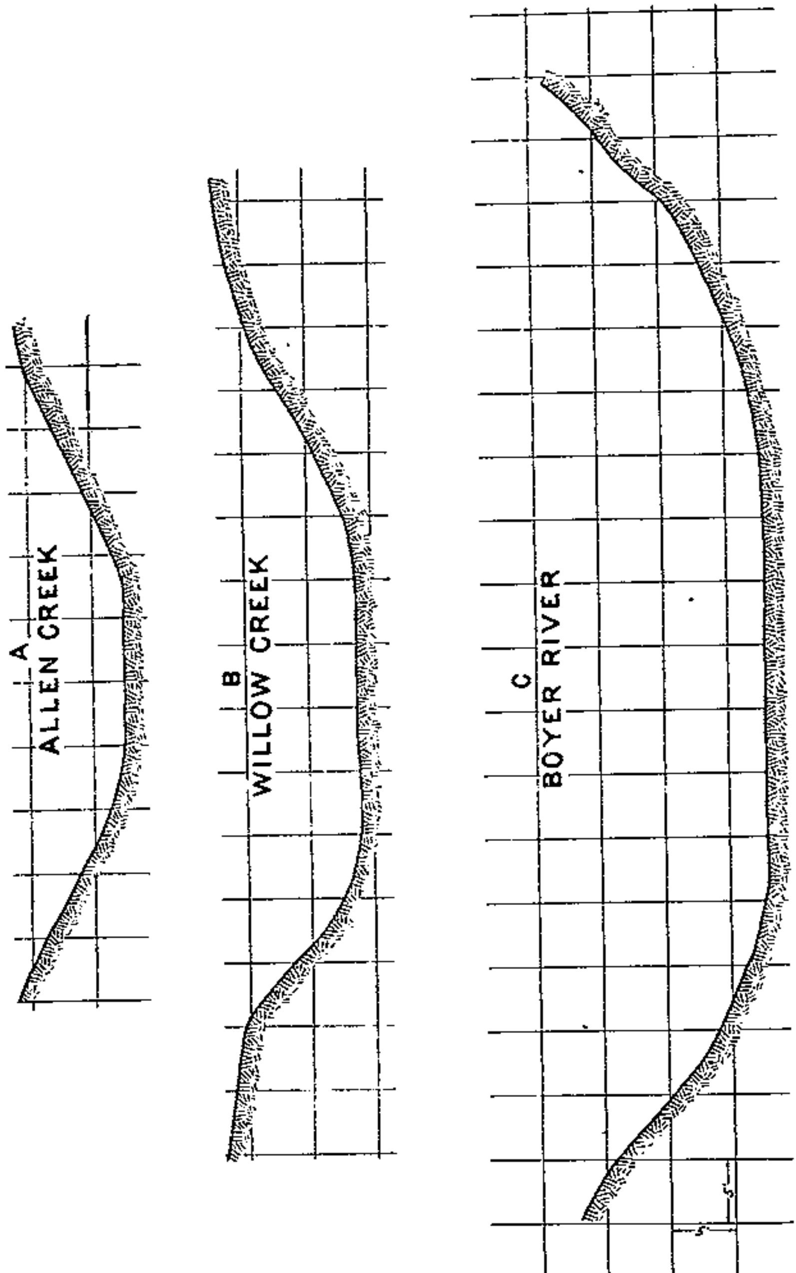
LITTLE SIOUX RIVER CUT-OFF DREDGED CHANNEL NEAR TURIN, IOWA, 1916

17	June 2, 1916	11.3	90.6	2,907.0	839.7	3.47	8.62	0.000480	54.0	0.042	*Course*, straight; 1,212 feet long. *Cross section*, slight variations in shape, abrupt variations in size. *Side slopes*, left side quite regular; right side irregular. *Bottom*, uneven and rather irregular. *Soil*, upper, dark silty loam; lower, heavy firm clay. *Condition*, considerable vegetation on both slopes of channel; very little silt in channel. *Constructed*, 1910. (Pl. 12, B and fig. 8, F.)
18	May 22, 1916	12.7	92.0	3,208.0	969.4	3.31	9.61	.000398	53.5	.044	
19	May 24, 1916	14.2	94.7	3,380.0	1,107.0	3.05	10.62	.000305	53.6	.046	
	----------	[1] 20.0	----------	----------	----------	----------	----------	----------	----------	----------	

LITTLE SIOUX RIVER CUT-OFF DREDGED CHANNEL NEAR TURIN, IOWA, 1917

20	June 9, 1917	18.8	113.2	4,505.5	1,332.8	3.38	10.77	0.000934	33.8	0.076	*Course*, straight; 1,654 feet long. *Cross section*, considerable variation in shape; very abrupt variations in size. *Side slopes*, left side, considerably rougher than during 1916; right side, extremely rough and irregular. *Bottom*, uneven and irregular. *Soil*, same as described next above. *Condition*, since 1916 measurements, right bank covered with trees and willows, which have slipped into channel; channel in very bad condition. *Constructed*, 1910. (Pl. 12, C and fig. 8, F.)
21	June 8, 1917	[1] 19.1	113.6	4,887.0	1,374.0	3.56	11.0	.000932	35.0	.075	

[1] Average maximum depth at bankful stage.


A
ALLEN CREEK
B
WILLOW CREEK
C
BOYER RIVER

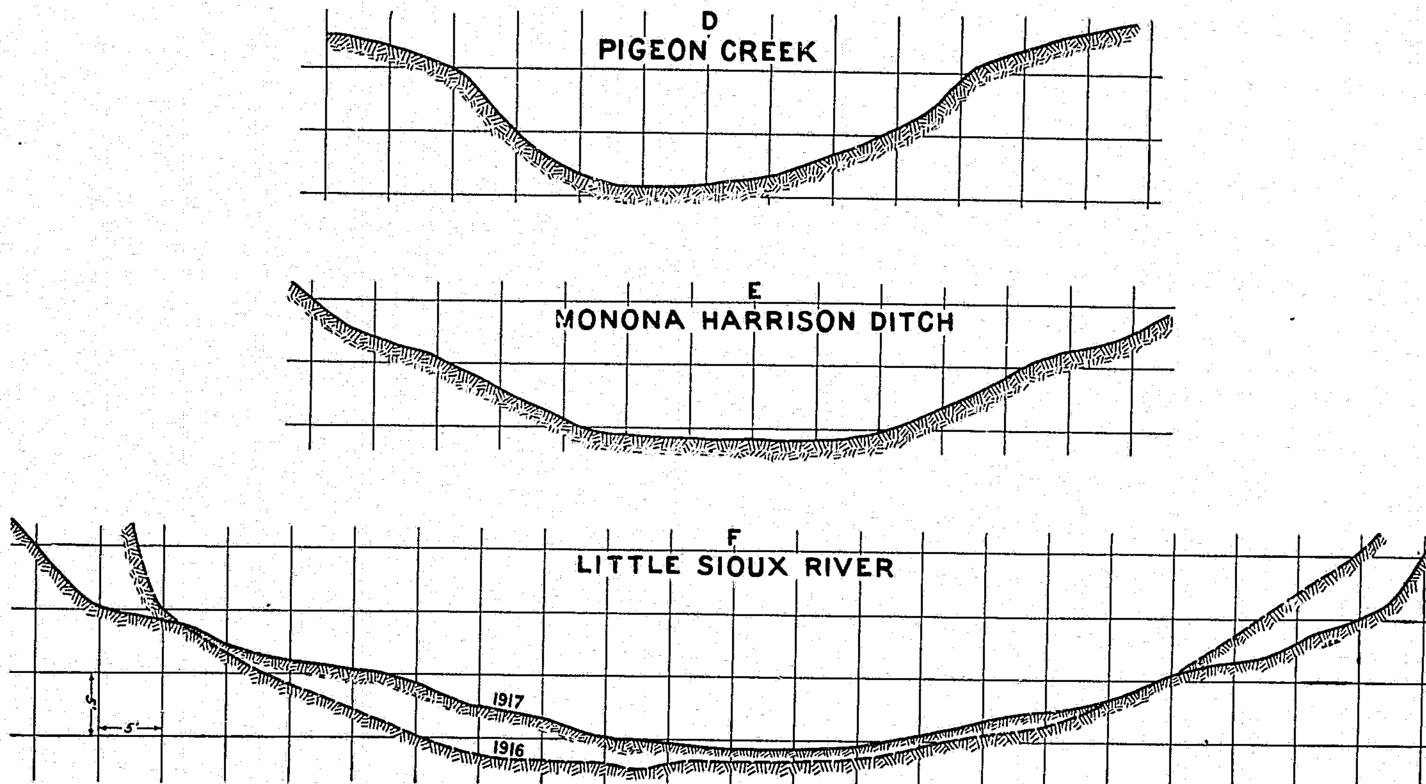


FIGURE 8.—Average cross sections of channels for experiments in western Iowa

It is not believed that a value of n less than 0.035 should be used in the design of small ditches such as Huggins Creek and Sugar Creek in this section of the country, or less than 0.30 for large ditches such as the South Forked Deer River at Roberts, where there is a fairly large low-water flow. Where it is desired to compute the capacity of an existing channel, the proper value of n can be selected by a comparison of the conditions in the channel with the conditions described for the various channels for which n has been determined in these experiments.

EXPERIMENTS IN WESTERN IOWA

Experiments in western Iowa were conducted in the following streams: Allen Creek, Willow Creek, Pigeon Creek, Boyer River, the Monona-Harrison Ditch, and Little Sioux River. The topography of the watersheds of these channels varies from rolling to hilly.

ALLEN CREEK

Gagings of Allen Creek were made from the first highway bridge north of the Chicago & North Western Railroad about 1 mile west of Missouri Valley. The upstream end of the course for slope measurements, which was 794 feet in length, was about 130 feet downstream from the bridge. A view of the slope course is shown in Plate 11, A. It is seen from this view and from Figure 8, A, that the course is straight and that the side slopes of the channel are very smooth and regular and stand at a slope of about 1½ to 1. No appreciable amount of vegetation can be seen in the channel. This stream was enlarged to its present size during the summer of 1916, and the measurements for values of n were made about one year later. The soil in the channel is a heavy dark loam. The bottom of the channel is generally covered with soft mud to a depth of one-half to 1 foot, and the side slopes, after high stages in the channel, are left covered with a coat of slippery slimy mud or silt. This coat can be seen by an inspection of Plate 11, A.

Two measurements of flow were made, for practically bankful stages. (Table 4, Nos. 1 and 2.) The value of n determined from each measurement was 0.014, which is exceedingly low for dredged drainage ditches and may be ascribed in part to the excellent condition of the channel and the uniformity of cross section (fig. 9, A), but mostly to the actual lining of the entire perimeter of the channel with a coating of slimy, slippery mud. This coating of mud no doubt greatly decreased the friction between the moving water and perimeter of the channel.

WILLOW CREEK

Discharge measurements of the Willow Creek dredged channel were made at the Chicago & North Western Railroad bridge near Missouri Valley. The slope posts for the upper end of the slope course were set about 155 feet below the bridge, the length of the course being 1,004 feet. It can be seen from Figures 8, B and 9, B, and Plate 11, B, that the slope course is straight and very uniform in cross section. The left side slope is much more regular and smooth than the right side slope, and resembles the slopes of the Allen Creek ditch in this respect. Some vegetation can be seen in the channel, but it was not present when the gagings and slope measurements were made. This channel is comparatively new, having been enlarged to its present size during the summer of 1916, and these measurements were made and views taken about one year later. The soil in the channel is a heavy dark loam, similar to that found in the Allen Creek channel. The bottom of the channel was covered with from 1 to 1½ feet of mud during these experiments, and the coating of the perimeter of the channel with slimy mud during high stages was practically the same as in Allen Creek. In general, the channel is very similar to that of Allen Creek, and the values of *n* obtained, as given in Table 4, are practically the same as those obtained for Allen Creek.

BOYER RIVER

Gagings of the Boyer River were made at the Lincoln Highway bridge about 1 mile from Missouri Valley. The downstream end of

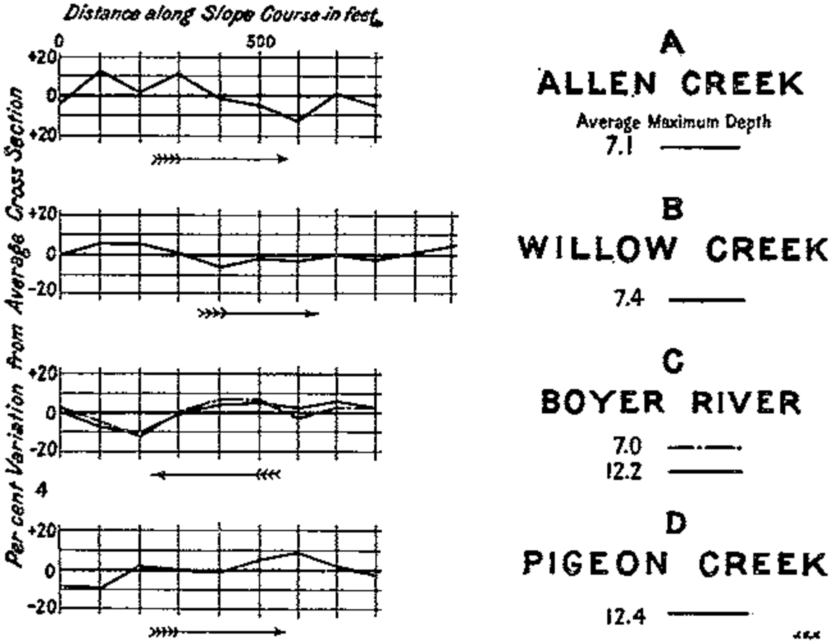


FIGURE 9.—Graphs for experiments in western Iowa, showing per cent variation from average cross-sectional area for all cross sections along slope courses

the slope course was 197 feet above the bridge. The length of the slope course was 868 feet. A view of the slope course looking upstream is shown in Plate 11, C. The downstream slope posts are barely visible on the left-hand side of the view, just beyond the break in the bank. It can be seen that beyond this break the course of the channel is straight and fairly uniform in cross section. (Fig. 9, C.) The sides of the upper part of the channel stand at a slope of about 1 to 1. (Fig. 8, C.) The soil in the upper part of the sides of the channel consists of a dark loam and in the lower part it is a hard yellow clay. The channel is practically free from any form of vegetation, which condition is largely due to its rapid enlargement caused by erosion. Since the channel was constructed, in 1910, it has enlarged to almost double its original size.

During flood stages the condition of the channel was very similar to that described for the Allen and Willow Creek channels. After the water subsided the sides of the channel were left coated with a thin layer of mud. The values of n obtained (Table 4) are higher than those obtained for Allen and Willow Creeks, which is attributed to the fact that the sides of the channel are considerably more irregular, as may be seen by comparing the views of the channels. Also, it is believed that the reduction of friction, due to the coating of mud on the sides of the channels, was much more effective on the rather flat side slopes of Willow and Allen Creeks than on the steeper side slopes of the Boyer River channel. It will be noted that, for the Boyer River channel, the value of n increases as the stage decreases. This is due, no doubt, to the fact that the lower part of the channel is more irregular than the upper part.

PIGEON CREEK

Gagings of Pigeon Creek were made at the highway bridge about one-half mile above the Chicago & North Western Railroad, near the town of Crescent. A view of the course of slope measurements is shown in Plate 12, A. This view was taken looking downstream from the gaging station. The upstream slope posts, which were about 65 feet below the bridge, can be seen on the right-hand side of the view.

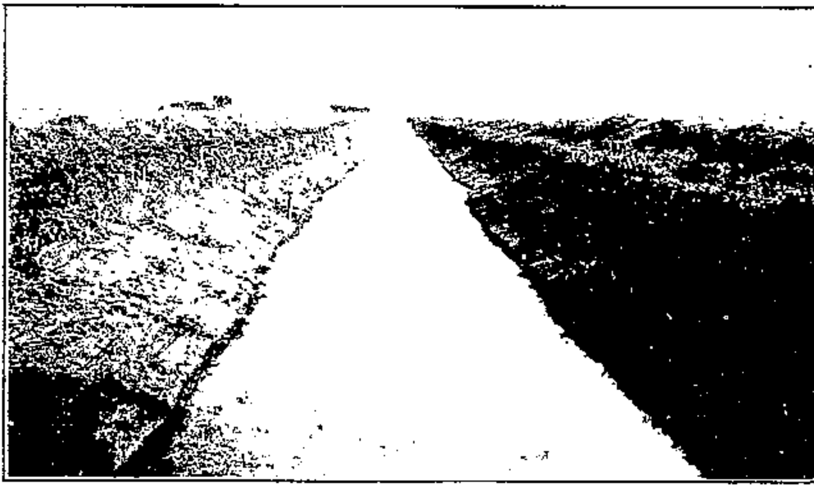
The upper portion of the sides of the channel stand at a slope of about 1 to 1. (Figs. 8, D and 9, D.) There was very little vegetation in the channel when the gagings and slope measurements were made. The soil in the channel is a heavy dark loam, and the bottom of the channel is generally covered with one-half to 1 foot of mud. The channel was dug in 1907, and has increased somewhat in depth since that time but not much in width. The right bank of the channel is rather smooth and regular, while the left bank is rough and irregular. During flood stages the channel was coated with mud, as described for the channels near Missouri Valley.

In Table 4, measurements 11 and 12, are shown two values of n obtained for high stages in the channel. These values are much larger than those obtained for Willow and Allen Creeks, which is perhaps due to the rougher condition and greater fall of the channel, both of which conditions probably rendered less effective the mud coating in reducing friction.

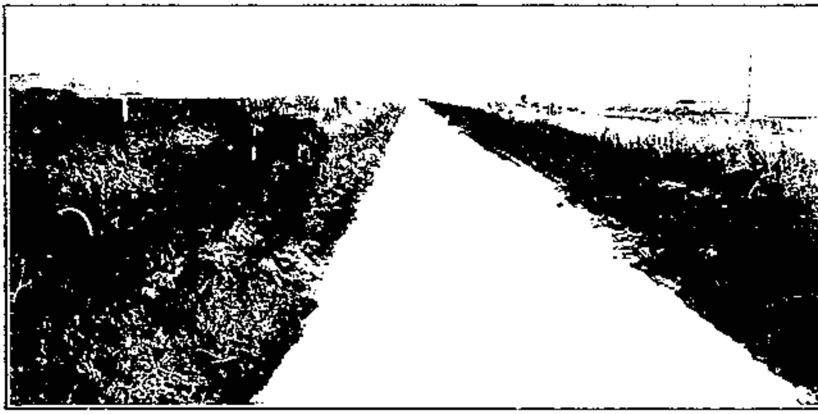
MONONA-HARRISON DITCH

A view of the slope course on the Monona-Harrison ditch, near Onawa, is shown in Plate 13, A. This view was taken looking upstream from the gaging station, which was located at the highway bridge on the Turin-Onawa road. The length of the slope course was 948 feet. Experiments were made during the years 1916 and 1917, and not much difference was found in the size and condition of the channel for the two sets of measurements.

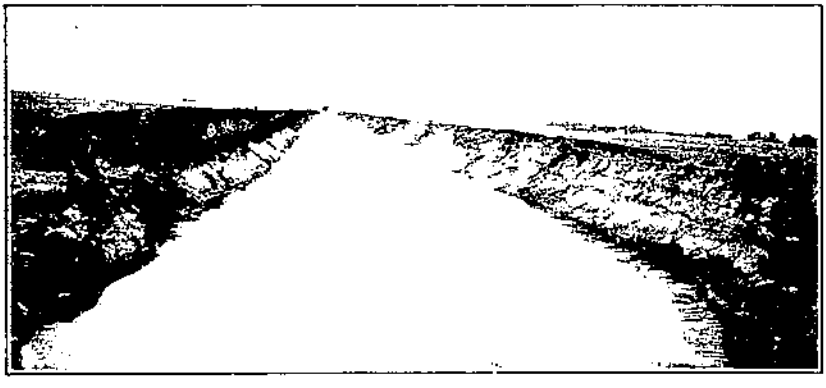
In Table 4 are given the values of n obtained for the years 1916 and 1917, respectively. From this table it is seen that the values of n obtained for the low stages during 1916 are lower than those obtained for the higher stages during 1917. This is due to the fact that the upper portion of the channel is irregular and covered with growth, as may be seen from the view of the channel. During the gagings



A



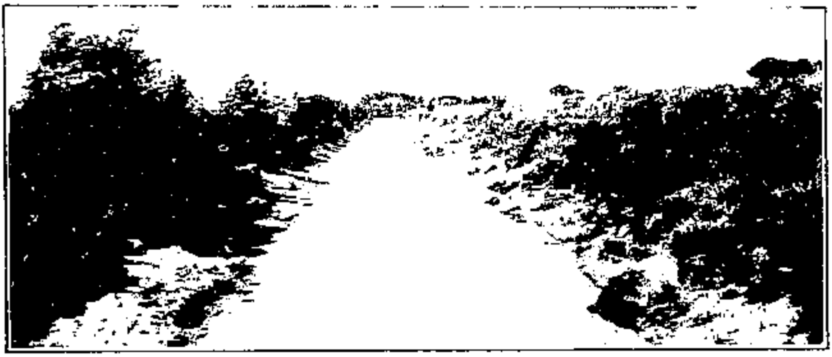
B



C

A, Allen Creek dredged channel near Missouri Valley, Iowa, looking down slope course, 1917; B, Willow Creek dredged channel near Missouri Valley, Iowa, looking down slope course, 1917; C, Boyer River dredged channel near Missouri Valley, Iowa, looking up slope course, 1917. (See Table 4)

A



B

C

A, Pigeon Creek dredged channel near Crescent, Iowa, looking down slope course, 1917; B, Little Sioux River cut-off dredged channel near Turin, Iowa, looking up slope course, 1916; C, Same view as B above, 1917. (See Table 4) and slope measurements the water was not as fully laden with silt as in the case of the ditches in the vicinity of Missouri Valley, nor were the sides of the channel so well coated with mud. The bed and the flatter portions of the sides of the channel were covered with silt, varying in depth from one-half to 1½ feet. (See fig. 8, E for average cross section of channel.)

LITTLE SIOUX RIVER CUT-OFF

Gagings of the Little Sioux River were made from the highway bridge on the Onawa-Turin Road, about one-half mile from Turin. Values of n for the channel were obtained during 1916 and 1917. Views of the slope course taken during June, 1916, and June, 1917, are shown in Plates 12, B and 12, C. The length of the slope course for the measurements made in 1916 was 1,212 feet, and for those made in 1917 was 1,654 feet. The slope course was located on the straight stretch of channel above the gaging station at the highway bridge. The soil in the upper part of the channel is a dark silty loam, while in the lower part it is a heavy firm clay. There was practically no silt in the bed of the channel during the time that the experiments were made. The channel during 1916 was fairly uniform in section, and the left bank, which is shown on the right-hand side of the view (pl. 12, B), was quite regular. The right bank was somewhat irregular, due to caving. (See fig. 8, F for average cross sections of the channel.) There was some vegetation on both side slopes as may be seen from the view. The values of n obtained shown in Table 4, are about what would be expected for a channel in its condition.

Plate 12, C shows the condition of the same channel in June, 1917. The right bank, which in 1916 was covered with trees, has caved into the channel, and the left bank is considerably rougher than it was in June, 1916. The two values of n obtained, 0.075 and 0.076, are considerably higher than those obtained in 1916. This may readily be ascribed to the caving of the right bank, which carried into the channel large trees and other obstructions. The water during the experiments was not laden with silt, as in the case of the ditches near Missouri Valley, and the channel was not coated with mud after the subsidence of the water.

DISCUSSION OF WESTERN IOWA EXPERIMENTS

The low values of n obtained for the Allen and Willow Creek ditches (0.013 to 0.014) are, so far as the writer knows, without precedent for dredged channels. From a close examination of the views of these courses, one would expect low values of n for channels with such regular and smooth side slopes and uniform cross sections. However, the fact that the values of n are so low can not be attributed alone to these conditions, since a low value of n was obtained for a bankful stage of the Boyer River Channel, which does not fulfill these ideal conditions of regularity and uniformity. The low values are therefore due mostly, no doubt, to the coating of slick, silty mud with which the perimeters of the channel were covered, the tendency being to smooth up irregularities. It is not conclusively apparent why the values of n for Pigeon Creek are so much higher than for Willow Creek since the conditions of the ditches are somewhat similar. It is possible that the slight difference in the condition of the channel and the greater fall rendered the mud coating less effective in reducing frictional resistance.

TABLE 5.—*Results of experiments made in North Carolina*

TURKEY BRANCH HAND-DUG CHANNEL NEAR PEMBROKE, N. C.

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
		Feet	*Feet*	*Second-feet*	*Sq. ft.*	*Ft. per sec.*	*Feet*				
1	Jan. 29, 1915	0.7	4.8	2.5	3.2	0.78	0.56	0.000915	34.5	0.032	*Course*, straight; 200 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 11, A. *Side slopes*, quite regular. *Bottom*, fairly regular; changes occur due to silting and erosion. *Soil*, sandy clay. *Condition*, free from vegetation of all kinds. *Constructed*, summer 1913. (Pl. 13, B and fig. 10, A.)
2	Jan. 14, 1915	.9	5.5	4.3	3.9	1.11	.62	.000790	50.2	.024	
3	Jan. 20, 1915	.95	5.7	4.7	4.0	1.17	.64	.001010	46.0	.027	
		[1] 5.0									

BACK SWAMP DREDGED CHANNEL NEAR LUMBERTON, N. C.

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula C	Coefficient of roughness n	Description of channel
4	Apr. 22, 1915	2.5	22.5	28.5	25.3	1.13	1.22	0.000792	36.3	0.038	*Course*, straight; 250 feet long. *Cross section*, abrupt variations in shape; for variation in size, see fig. 11, B. *Side slopes*, fairly regular. *Bottom*, fairly regular, some holes. *Soil*, sandy clay. *Condition*, mat of overhanging ragged roots on both side slopes; no weeds or grass in channel; some roots in bottom. *Constructed*, winter 1913. (Pl. 13, C and fig. 10, B.)
5	Feb. 10, 1915	2.9	23.1	40.0	32.0	1.25	1.45	.000880	35.0	.042	
6	May 17, 1915	3.1	23.3	58.6	35.6	1.65	1.57	.000880	44.4	.034	
7	Feb. 3, 1915	4.4	24.6	129.6	66.0	1.96	2.51	.000624	49.5	.034	
8	Jan. 20, 1915	5.1	25.2	171.9	83.1	2.07	2.98	.000600	49.0	.036	
9	May 13, 1915	5.7	25.8	232.5	98.8	2.35	3.34	.000730	47.7	.038	
10	Jan. 25, 1915	5.75	26.0	235.1	99.3	2.37	3.34	.00064[illegible]	51.2	.036	
		[1] 6.5									

JACOB SWAMP DREDGED CHANNEL AT LOVETT ROAD, NEAR LUMBERTON, N. C.

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula C	Coefficient of roughness n	Description of channel
11	Feb. 22, 1915	1.5	22.3	6.5	13.0	0.50	0.67	0.000493	27.6	0.040	*Course*, straight; 300 feet long. *Cross section*, rather abrupt variations in shape; for variation in size, see fig. 11, C. *Side slopes*, fairly regular. *Bottom*, fairly even and regular. *Soil*, sandy clay loam. *Condition*, not much vegetation in channel, except for last measurement, at which time two-thirds of the bottom and side slopes were covered with water grass. *Constructed*, April, 1913. (Pl. 14, A and fig. 10, C.)
12	Jan. 19, 1915	2.2	24.4	30.1	28.3	1.06	1.19	.000317	54.6	.026	
13	Jan 25, 1915	2.3	24.7	32.0	29.8	1.07	1.23	.000443	45.7	.031	
14	Feb. 2, 1915	2.5	25.2	43.7	35.0	1.25	1.41	.000373	54.6	.027	
15	May 13, 1915	3.2	26.0	51.0	49.4	1.03	1.81	.000550	32.6	.048	
		[1] 6.0									

LITTLE JACOB SWAMP DREDGED CHANNEL NEAR LUMBERTON, N. C., DURING WINTER MONTHS

16	Feb. 22, 1915	0.9	13.0	6.5	10.3	0.63	0.69	0.000448	35.8	0.033	*Course*, straight; 500 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 11, D. *Side slopes*, fairly regular. *Bottom*, quite even and regular. *Soil*, clay; sandy bottom due to silting. *Condition*, some moss along course; very little foreign material in channel. *Constructed*, July, 1913. (Pl. 14, B and Fig. 10, D.)
17	Jan. 13, 1915	1.0	13.6	13.7	12.4	1.10	.79	.000738	45.4	.028	
18	Jan. 19, 1915	1.5	17.2	24.1	19.6	1.23	1.08	.000630	47.1	.029	
19	Jan. 25, 1915	1.6	17.5	26.7	20.5	1.30	1.11	.000566	52.0	.027	
		[1] 7.0									

LITTLE JACOB SWAMP DREDGED CHANNEL NEAR LUMBERTON, N. C., DURING SUMMER MONTHS

20	June 28, 1915	0.65	10.0	2.2	6.3	0.35	0.50	0.000308	28.2	0.036	*Course*, same as next above. *Condition*, light growth of grass and weeds along edge of low water flow.
21	June 15, 1915	.7	10.5	2.8	6.8	.41	.53	.000314	31.7	.034	
22	June 11, 1915	.8	11.0	4.5	8.6	.52	.62	.000322	36.8	.031	
23	May 19, 1915	.9	12.0	5.4	10.1	.53	.70	.000360	33.3	.035	
24	May 15, 1915	1.4	17.0	15.4	17.4	.89	1.01	.000318	49.7	.027	
25	May 13, 1915	2.2	20.0	29.5	32.9	.90	1.55	.000176	54.5	.028	
		[1] 7.0									

JACOB SWAMP DREDGED CHANNEL AT R. & C. R. R., NEAR LUMBERTON, N. C., DURING WINTER MONTHS

26	Mar. 4, 1915	1.1	19.5	9.6	14.9	0.64	0.67	0.000593	32.1	0.036	*Course*, straight; 300 feet long. *Cross section*, rather abrupt variations in shape; for variation in size, see fig. 11, E. *Side slopes*, irregular. *Bottom*, fairly even and regular. *Soil*, clay loam. *Condition*, some roots and dead vegetation in channel. *Constructed*, April, 1913. (Pl. 14, C and fig. 10, E.)
27	Feb. 22, 1915	1.3	20.8	17.7	19.2	.92	.84	.000470	46.2	.028	
28	Jan. 19, 1915	2.3	25.1	64.3	47.7	1.35	1.72	.000503	45.9	.036	
29	Jan. 25, 1915	2.4	25.9	71.1	49.7	1.43	1.78	.000350	57.2	.028	
30	Feb. 2, 1915	2.9	26.3	112.8	65.2	1.73	2.21	.000531	50.5	.033	
		[1] 6.5									

JACOB SWAMP DREDGED CHANNEL AT R. & C. R. R., NEAR LUMBERTON, N. C., DURING SUMMER MONTHS

31	June 11, 1915	1.2	19.0	8.9	22.4	0.40	0.93	0.000560	17.6	0.068	*Course*, same as next above. *Condition*, growth of water grass and weeds in channel.
32	May 19, 1915	1.4	20.2	11.8	25.6	.46	1.05	.000590	18.4	.068	
33	May 17, 1915	1.6	21.0	20.6	31.2	.66	1.25	.000483	26.8	.051	
34	May 15, 1915	2.1	23.2	37.8	43.8	.86	1.64	.000437	32.0	.047	
35	May 13, 1915	3.4	27.7	96.2	79.4	1.21	2.56	.000423	36.7	.047	
		[1] 6.5									

[1] Average maximum depth at bankful stage.

In view of the results obtained for Pigeon Creek, the Monona-Harrison Ditch, and the lower part of the Boyer River Channel, it is possible that the effectiveness of this coating of mud in reducing friction is affected by vegetation, roughness of channel, angle of side slopes, irregularity of cross section, and slope of channel. It is not recommended that such low values of *n* as obtained for Allen and Willow Creeks be employed in the design of proposed dredged drainage channels unless there is no question but that all the conditions of the Allen and Willow Creek Channels will be duplicated. It should also be remembered that these ditches are comparatively new, and unless the proposed ditches are to be carefully maintained to keep the channels free of growth and obstructions, and unless there is good reason to believe that they will retain their original smooth slopes and uniform cross section, a low value of *n* should not be used, even though the silty conditions as described above could be expected to prevail.

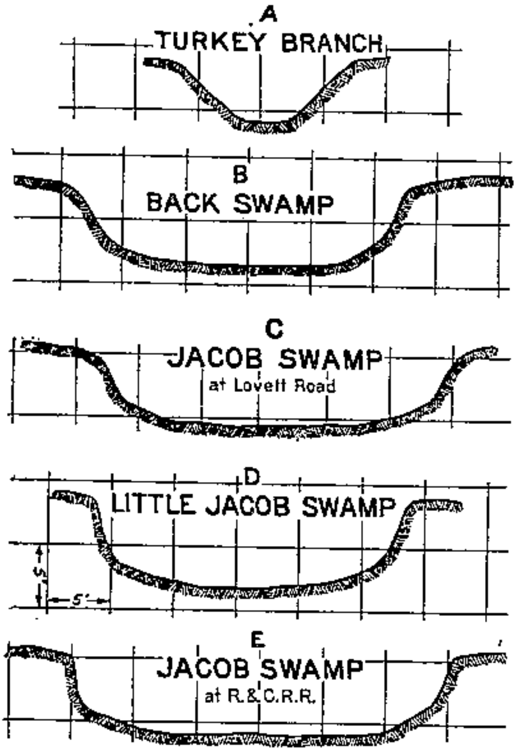


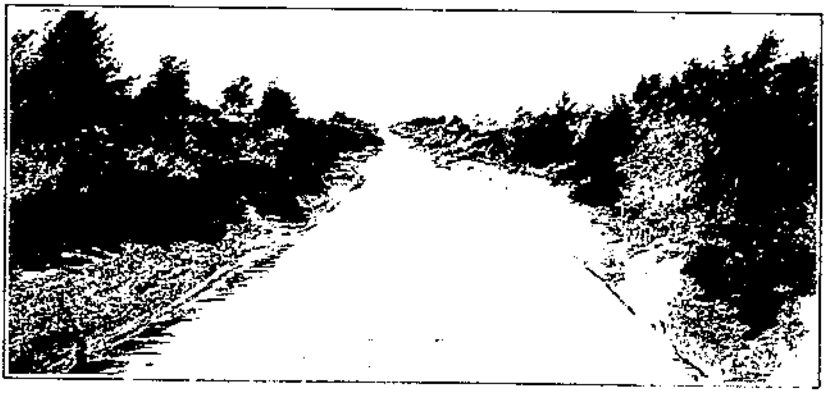
FIGURE 10.—Average cross sections of channels for experiments in North Carolina

EXPERIMENTS IN SOUTHERN NORTH CAROLINA

Values of *n* were determined for five courses of channels in Back Swamp and Jacob Swamp Drainage District in Robeson County, N. C., namely: Turkey Branch, Back Swamp, Jacob Swamp at Lovett Road, Little Jacob Swamp, and Jacob Swamp at the Raleigh & Charleston Railroad. The topography of the watersheds of these ditches is quite flat.

TURKEY BRANCH

A straight course 200 feet long was selected for slope measurements on the Turkey Branch Channel just above the Atlantic Coast Line Railroad southwest of Pembroke. This channel is small and was hand-dug. (Pl. 13, B and fig. 10, A.) At the time of the experiments the channel was very uniform in cross section for a bankful stage; it had regular side slopes and was free from growth of any kind. The values of *n* obtained were only for very low stages. As may be seen from Table 5, the average maximum depth for the channel at bankful stage was 5.0 feet, and only 0.95 foot for the



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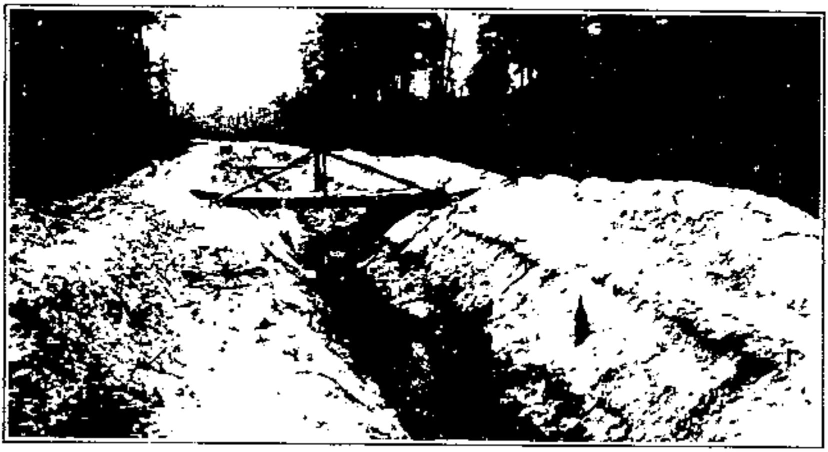
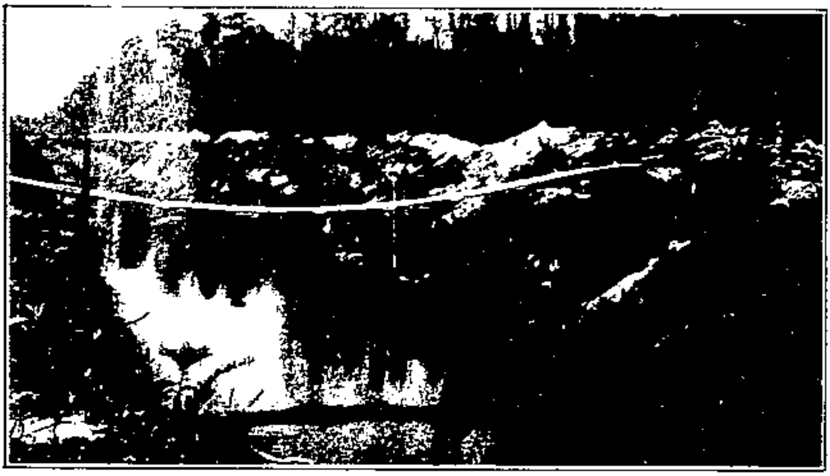


B

C

A, Monona Harrison dredged channel near Onawa, Iowa, looking up slope course, 1916 (see Table 49); B, Turkey Branch dredged channel near Pembroke, N. C., slope course, 1915 (see Table 50); C, Back Swamp dredged channel near Lumberton, N. C., slope course, 1915 (see Table 5)

A



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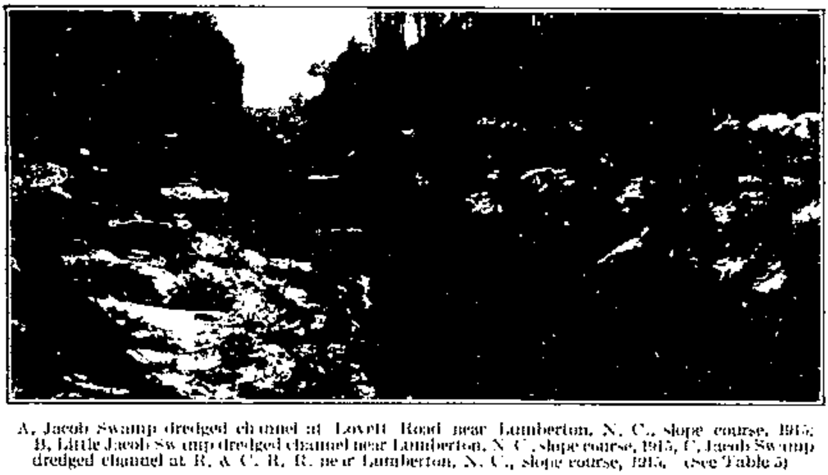


C

A, Jacob Swamp dredged channel at Lovett Road near Lumberton, N. C., slope course, 1915; B, Little Jacob Swamp dredged channel near Lumberton, N. C., slope course, 1915, C, Jacob Swamp dredged channel at R. & C. R. R. near Lumberton, N. C., slope course, 1915. (See Table 5)

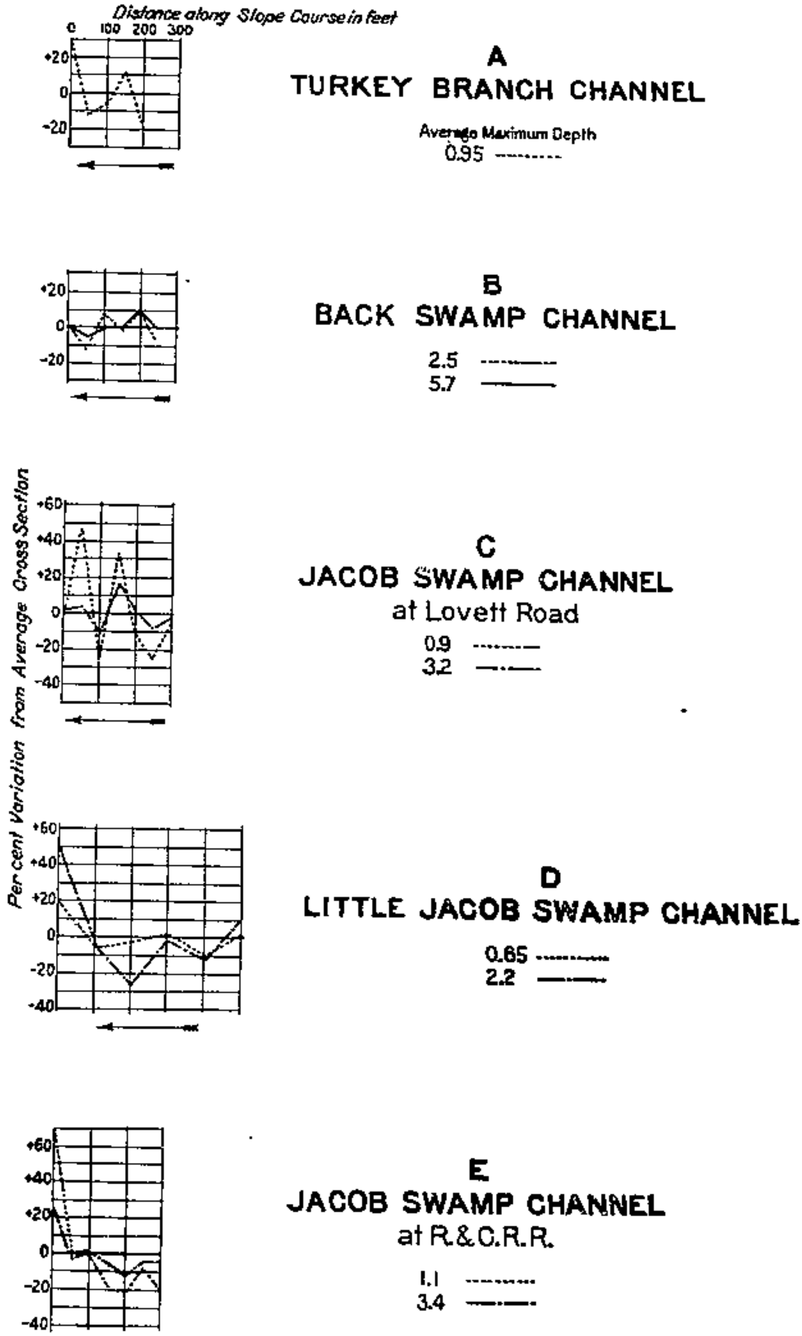


FIGURE 11.—Graphs for experiments in North Carolina showing per cent variation from average cross-sectional area for all cross sections along slope courses

highest stage for which n was determined. The cross sectional area of the lower part of the channel varied considerably in size. (Fig. 11, A.)

BACK SWAMP

A straight course of channel 250 feet in length was used for slope measurements on the Back Swamp channel. It was located just west of the Sunday Ford Road and about 8 miles west of Lumberton. At the time of these measurements the channel was quite uniform in cross section, and the side slopes were quite regular. (Fig. 11, B.) The side slopes have been eroded considerably so as to be nearly vertical, leaving a mat of overhanging ragged roots on either bank. Owing to a comparatively swift current, there were no weeds, grass, or other vegetation on the bottom or side slopes, but there were a number of large tree roots in the channel. Plate 13, C and Figure 10, B show the condition and average cross section of channel, and Table 5 shows the values obtained for n. Of the five channels for which experiments were made, this is the only one where a value of n was determined for a near bankful stage.

JACOB SWAMP AT LOVETT ROAD

A slope course 300 feet in length, just west of the Lovett Road and about 2 miles south of Lumberton, was selected for slope measurements on this channel. The cross section was fairly uniform for the higher stages, and the side slopes and bottom fairly regular. For the lower stages there was considerable variation in cross section. (Fig. 11, C.) There was practically no vegetation in the channel when the measurements were made during January and February, but for the single measurement made during May about two-thirds of the bottom and sideslopes were covered with water grass. (See pl. 14, A, for view and Fig. 10, C, for average cross section of the channel.)

During low water the thread of the stream wanders from side to side, which, with the large and abrupt variations in cross section, is no doubt responsible for the high value of n obtained for the lowest stage. (Measurement 11, Table 5.) The high value obtained for measurement 15 is due, of course, to the growth of grass in the channel. This value was obtained for about half-bankful stage. Values for higher stages were not obtained, so that none of the values of n given in Table 5 apply to the channel when flowing full.

LITTLE JACOB SWAMP

A straight course 500 feet in length, just west of the Lovett road about 2½ miles south of Lumberton, was used for slope measurements. This course was fairly uniform in cross section for a distance of about 450 feet from the upper end of the slope course, with quite regular side slopes and bottom. (Fig. 11, D.) There was very little growth in the channel during the winter months. Plate 14, B, is a view of the channel and Figure 10, D, shows the average cross section. During the summer months grass and weeds appear in the channel, especially along the edge of the water, and there were several patches of moss along the slope course. There was not sufficient growth in the channel to produce a very marked effect upon the value of n, as may be seen from the small difference in the results of the measurements as given in Table 5 for the winter and summer months. The values of n were obtained for only very low stages.

JACOB SWAMP AT RALEIGH & CHARLESTON RAILROAD

The slope course used on this channel was 300 feet in length and was located just west of the Raleigh & Charleston Railroad trestle, about 2 miles south of Lumberton. The cross section of this course of channel was fairly uniform for a distance of about 275 feet from the upper end of the course, but the side slopes were rather irregular. (Fig. 11, E.) There were some roots and dead vegetation in the channel during the winter months. Silting had occurred along the course, and there was a mud island 3 feet wide by 10 feet long lying lengthwise of the channel a short distance above the lower end of the slope course. During the summer months the island was covered with water grass. There was also a growth of grass along the edge of low-water stages and two patches of grass in the channel along the course. Plate 14, C, is a view of the channel, and Figure 10, E, shows the average cross section.

The highest stages for which values of n were determined were about half-bankful. Referring to Table 5, it can be seen that the values of n obtained during the summer months are higher than those obtained during the winter months, owing to the growth of grass in the channel; also that the values for the summer months increase as the stage decreases, due no doubt to the fact that for the lower stages the grass filled a much greater proportion of the cross-sectional area of the channel.

DISCUSSION OF NORTH CAROLINA EXPERIMENTS

Attention is especially called to the fact that in these experiments values of n were not obtained for bankful stages, and this should be kept in mind when comparing the views and descriptions of the channels with the values of n obtained. A value of n for a near-bankful stage was obtained on the Back Swamp channel, but in the other channels the highest stages for which values of n were determined were about half, and in some instances considerably less than half, of a bankful stage.

The chief value of these experiments lies in the fact that values of n were determined before and after the growth of grass in three of the channels, from which a general idea can be obtained as to the retarding effect of grass upon the flow in water courses.

With the exception of Back Swamp the discharges of the channels were quite small, and for this reason it is not believed that the results are as accurate as were obtained for the other experiments herein discussed, since the effect of errors in making small discharge measurements is usually greater than in the measurement of large discharges.

EXPERIMENTS IN EASTERN FLORIDA

These experiments were made on the main channels of the Fellsmere, Vero, and Fort Pierce drainage districts, and on two courses of lateral No. 2 of the Fort Pierce drainage district. The topography of the watersheds of these ditches is comparatively flat.

TABLE 6.—*Results of experiments made in Florida*

MAIN DREDGED CHANNEL NEAR FELLSMERE, FLA., 1916

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
		Feet	*Feet*	*Second-feet*	*Sq. ft.*	*Ft. per sec.*	*Feet*				
1	Oct. 12, 1916	1.40	45.5	48.8	48.2	1.01	1.05	0.000328	54.5	0.025	*Course*, straight; 2,000 feet long. *Cross section*, slight variations in shape; for variation in size, see fig. 13, A. *Side slopes*, lower, fairly regular; upper, rather irregular. *Bottom*, regular and even. *Soil*, coarse sand on bottom, clay on sides. *Condition*, some vegetation, principally dog fennel, for higher stages; practically no vegetation for lower stages. *Constructed*, November, 1911. (Pl. 15, A.)
2	Dec. 5, 1916	1.7	46.4	64.7	63.1	1.02	1.32	.000260	55.1	.026	
3	Sept. 22, 1916	5.6	75.6	506.2	298.0	1.70	3.83	.000222	58.3	.032	
4	do	5.7	76.5	534.0	302.2	1.77	3.83	.000198	64.2	.029	
5	do	5.75	76.5	558.6	314.8	1.77	3.97	.000205	62.3	.030	
		[1] 15.9									

MAIN DREDGED CHANNEL NEAR FELLSMERE, FLA., 1917

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
6	Feb. 10, 1917	1.6	45.6	44.2	48.1	0.92	1.05	0.000259	55.8	0.025	Condition of channel practically the same as during the 1916 measurements. For variation in size of channel see fig. 13, B. See fig. 12, B, for cross section.
7	July 12, 1917	2.3	49.3	94.7	83.1	1.14	1.66	.000235	57.8	.027	
8	Oct. 18, 1917	3.2	53.5	186.4	127.7	1.46	2.33	.000236	62.1	.027	
9	Sept. 29, 1917	5.0	68.8	403.1	241.4	1.67	3.15	.000200	66.5	.027	
10	do	7.6	88.5	746.8	441.9	1.69	4.86	.000185	56.3	.036	
		[1] 15.9									

MAIN DREDGED CHANNEL NEAR FELLSMERE, FLA., 1920

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
11	Oct. 26, 1920	1.9	48.0	47.4	79.0	0.60	1.29	0.0001325	45.9	0.030	Same course of channel was used as for the 1916 and 1917 measurements. A little more vegetation in channel than at time of former measurements and channel more irregular. For variation in size of channel, see fig. 13, C.
12	Sept. 14, 1920	2.4	50.9	85.5	101.8	.84	2.00	.000140	50.2	.031	
13	Aug. 9, 1920	3.1	55.4	124.4	136.7	.91	2.43	.0001305	51.1	.033	
14	Aug. 30, 1920	3.7	59.6	159.7	171.7	.93	2.82	.0001095	52.9	.033	
15	Sept. 10, 1920	4.0	62.0	224.6	190.3	1.18	3.01	.0001365	58.2	.030	
		[1] 15.9									

MAIN DREDGED CHANNEL NEAR VERO, FLA., 1916

16	Aug. 14, 1916	1.2	47.7	41.1	44.6	0.92	0.92	0.000625	38.3	0.034	*Course*, straight; 1,000 feet long. *Cross section*, slight variations in shape; for variation in size, see fig. 13, D. *Side slopes*, fairly uniform and regular for lowest three stages; rough and irregular for highest two. *Bottom*, fairly even and regular. *Soil*, sand on bottom, clay on sides. *Condition*, some vegetation in lower part of channel; flat sand bars. *Constructed*, December, 1912. (Pl. 16, A, and fig. 12, D.)
17	Nov. 21, 1916	2.2	52.8	131.2	91.4	1.44	1.70	.000478	50.4	.032	
18	Oct. 5, 1916	2.8	55.9	201.4	128.6	1.57	2.25	.000305	60.0	.028	
19	Oct. 28, 1916	5.3	67.2	569.5	285.7	1.99	4.11	.000479	44.9	.043	
20	Oct. 20, 1916	6.9	73.1	955.2	397.3	2.40	5.26	.000538	45.1	.046	
	----------	[1] 10.0	----------	----------	----------	----------	----------	----------	----------	----------	

MAIN DREDGED CHANNEL NEAR VERO, FLA., 1917

21	Sept. 12, 1917	3.2	57.9	290.2	136.9	2.12	2.33	0.000406	69.0	0.024	Condition of channel, about the same as for the 1916 measurements. For variation in size of channel see fig. 13, E.
22	Oct. 19, 1917	4.7	67.6	533.2	234.9	2.27	3.41	.000407	61.1	.030	
23	Sept. 27, 1917	5.1	68.9	577.2	260.0	2.22	3.68	.000416	56.8	.033	
24	Sept. 25, 1917	5.7	71.3	712.5	307.1	2.32	4.18	.000571	47.6	.040	
	----------	[1] 10.0	----------	----------	----------	----------	----------	----------	----------	----------	

MAIN DREDGED CHANNEL NEAR VERO, FLA., 1920

25	Aug. 17, 1920	2.4	40.1	54.9	74.2	0.74	1.95	0.000175	40.1	0.039	Same course of channel was used as for 1916 and 1917 measurements. Channel, a little more irregular and contained more vegetation than for former measurements. For variation in size of channel, see fig. 13, F.
26	Sept. 11, 1920	2.9	42.5	74.4	91.9	.81	2.35	.000163	41.4	.040	
27	Sept. 28, 1920	4.0	52.0	175.3	144.9	1.21	2.61	.000248	47.6	.036	
28	Sept. 25, 1920	4.9	59.4	274.7	197.6	1.39	3.02	.000294	46.6	.038	
	----------	[1] 10.0	----------	----------	----------	----------	----------	----------	----------	----------	

MAIN DREDGED CHANNEL NEAR FORT PIERCE, FLA., 1916

29	Dec. 8, 1916	1.7	23.0	6.9	29.9	0.23	1.26	0.000125	18.3	0.070	*Course*, straight; 1,032 feet long. *Cross section*, not much variation in shape; for variation in size, see fig. 13, G. *Side slopes*, rather irregular. *Bottom*, rather rough. *Soil*, hard clay. *Condition*, some water weeds on bottom; growth of grass and lilies near water edge at low stage. (Pl. 15, B; and fig. 12, G.)
30	Nov. 7, 1916	3.5	28.3	62.8	74.2	.85	2.62	.000178	39.3	.044	
31	Nov. 18, 1916	3.7	30.6	77.5	79.5	.98	2.62	.000161	47.6	.036	
32	Nov. 4, 1916	5.1	32.2	139.3	125.8	1.11	3.56	.000199	41.7	.045	
33	Oct. 28, 1916	5.4	32.9	149.6	135.0	1.11	3.77	.000203	40.1	.048	
	----------	[1] 9.0	----------	----------	----------	----------	----------	----------	----------	----------	

MAIN DREDGED CHANNEL NEAR FORT PIERCE, FLA., 1917

34	Sept. 13, 1917	2.9	20.3	13.4	37.3	0.36	1.73	0.000070	32.7	0.045	*Course*, straight; 900 feet long. *Cross section*, not much variation in shape; variation in size, see fig. 13, H. *Side slopes*, fairly regular. *Bottom*, irregular. *Soil*, hard clay. *Condition*, very little vegetation; channel was cleaned out and deepened since the 1916 measurements were made. (Fig. 12, H.)
35	Oct. 22, 1917	5.0	25.6	106.4	87.2	1.22	3.06	.000163	54.5	.033	
36	Oct. 20, 1917	5.8	26.8	155.8	109.7	1.42	3.58	.000180	56.0	.033	
37	Sept. 25, 1917	6.7	28.5	220.2	134.3	1.64	4.02	.000220	55.1	.035	
38	Oct. 17, 1917	6.9	28.1	234.1	138.5	1.69	4.09	.000212	57.3	.033	
	----------	[1] 11.5	----------	----------	----------	----------	----------	----------	----------	----------	

[1] Average maximum depth at bankful stage.

TABLE 6.—*Results of experiments made in Florida*—Continued

MAIN DREDGED CHANNEL NEAR FORT PIERCE, FLA., 1920

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
		Feet	*Feet*	*Second-feet*	*Sq. ft.*	*Ft. per sec.*	*Feet*				
39	July 26, 1920	4.1	48.5	57.3	150.7	0.38	3.16	0.000166	16.6	0.108	*Course*, straight; 900 feet long. *Cross section*, slight variation in shape; for variation in size, see fig. 13, I. *Side slopes*, irregular, overhanging banks in places. *Bottom*, somewhat irregular. *Soil*, hard clay on sides, sandy in bottom due to silting. *Condition*, considerable silting, dense lily growth in upper end of slope course. *Constructed*, redredged in 1920, both widened and deepened. (Pl. 15, C, and fig. 12, I.)
40	Sept. 27, 1920	5.5	52.6	181.2	229.4	.79	4.17	.000181	28.8	.068	
41	Sept. 23, 1920	5.7	53.1	227.8	255.9	.89	4.52	.000150	34.2	.059	
42	Sept. 25, 1920	6.3	53.8	266.4	271.8	.98	4.57	.000149	37.6	.053	
		[1] 13.0									

LATERAL DREDGED CHANNEL NO. 2, COURSE A, NEAR FORT PIERCE, FLA.

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient C	Coefficient n	Description of channel
43	Oct. 20, 1917	3.9	19.5	12.5	52.3	0.24	2.38	0.000027	29.9	0.054	*Course*, straight; 503 feet long. *Cross section*, slight variations in shape; for variation in size, see fig. 13, J. *Side slopes*, rather irregular. *Bottom*, slightly irregular. *Soil*, hard clay. *Condition*, some vegetation in channel. (Pl. 16, B and fig. 12, J.)
44	Oct. 17, 1917	5.0	22.0	37.6	75.1	.50	2.87	.000064	36.9	.047	
		[1] 8.5									

LATERAL DREDGED CHANNEL NO. 2, COURSE B, NEAR FORT PIERCE, FLA.

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient C	Coefficient n	Description of channel
45	Oct. 20, 1917	2.2	30.1	10.5	38.8	0.27	1.27	0.000721	8.9	0.140	*Course*, straight; 500 feet long. *Cross section*, slight variations in shape; for variation in size, see fig. 13, K. *Side slopes*, rather irregular. *Bottom*, fairly regular; occasional low pockets that hold water during periods of no flow. *Soil*, sandy and easily eroded. *Condition*, bad; channel practically covered with vegetation. (Pl. 16, C and fig. 12, K.)
46	Oct. 17, 1917	3.3	39.4	31.4	76.7	.41	1.96	.000423	14.2	.108	
		[1] 4.0									

[1] Average maximum depth at bankful stage.

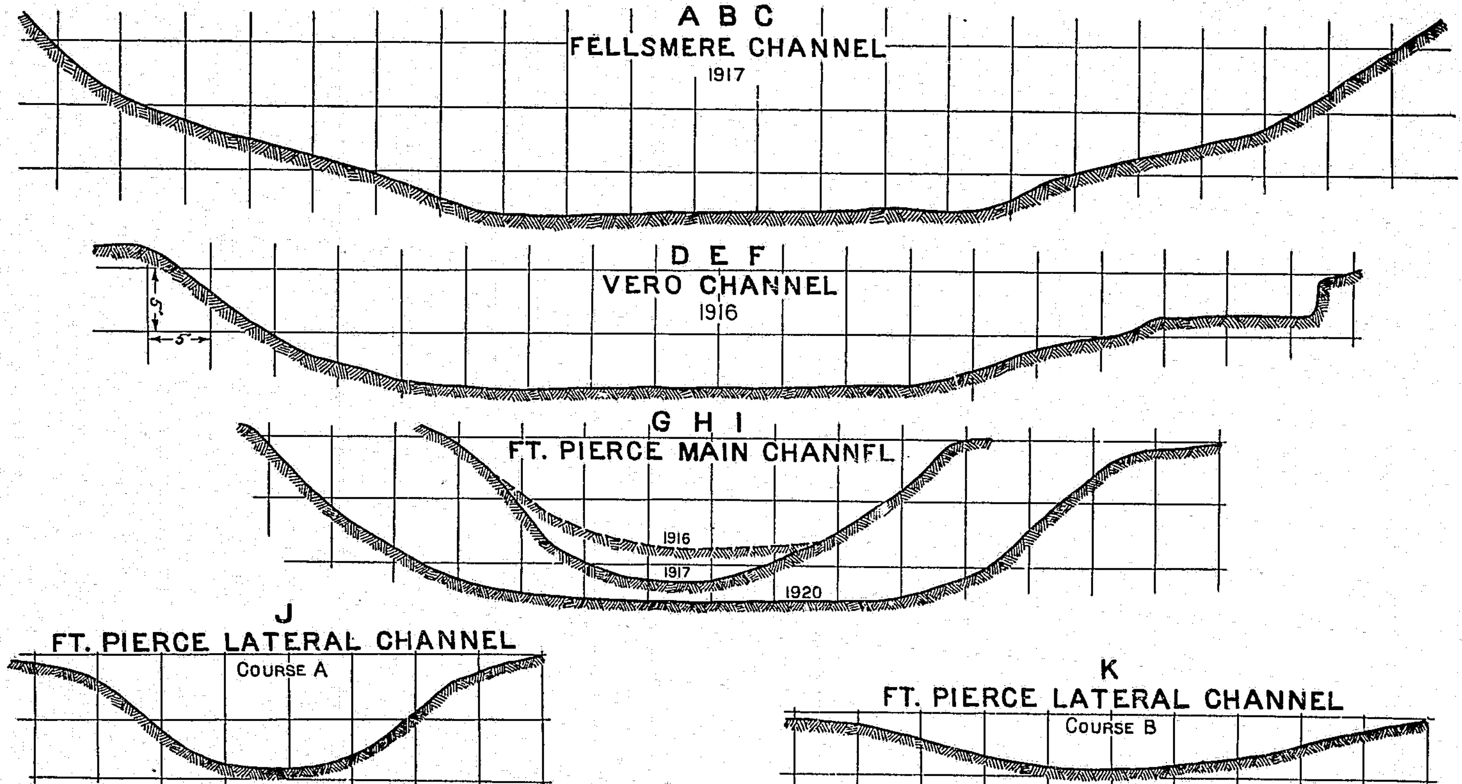


FIGURE 12.—Average cross sections of channels for experiments in Florida

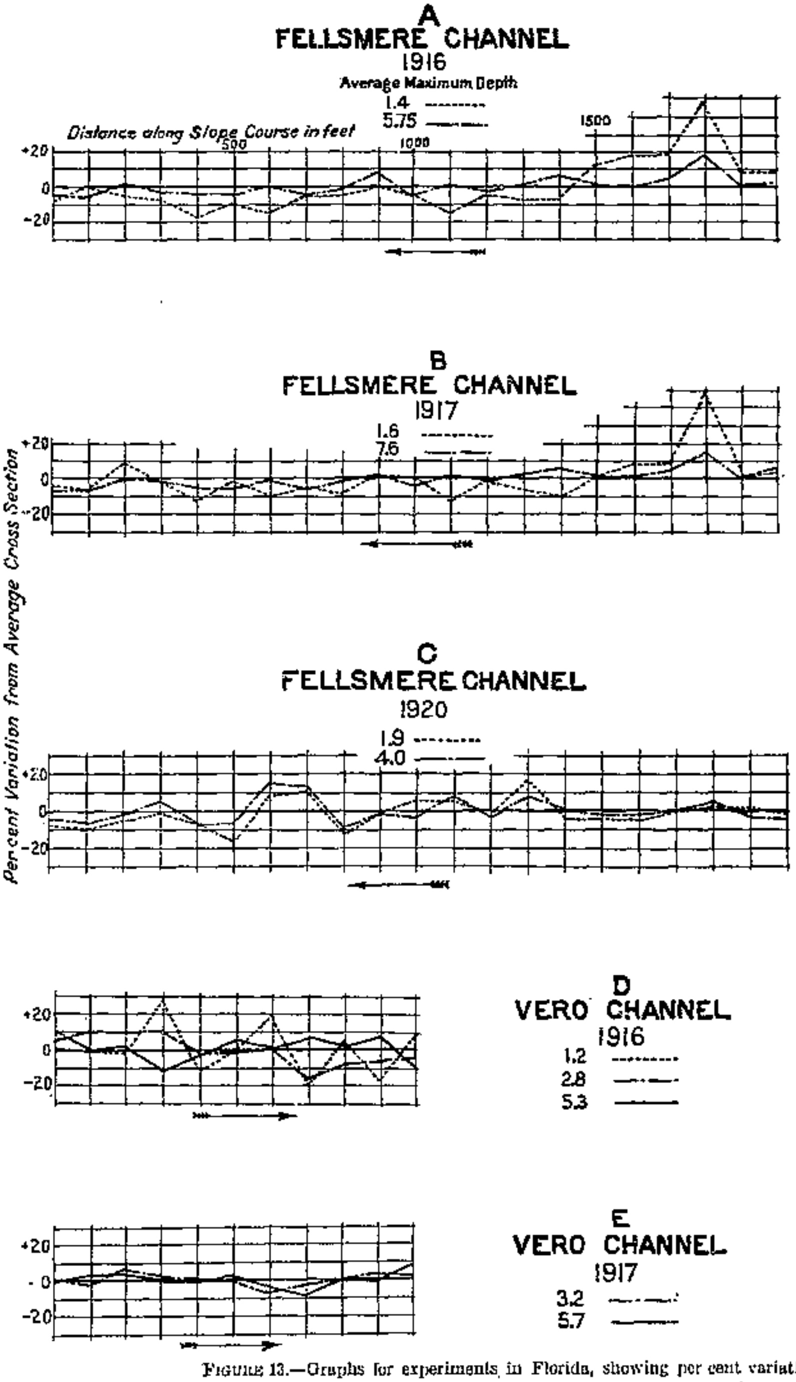
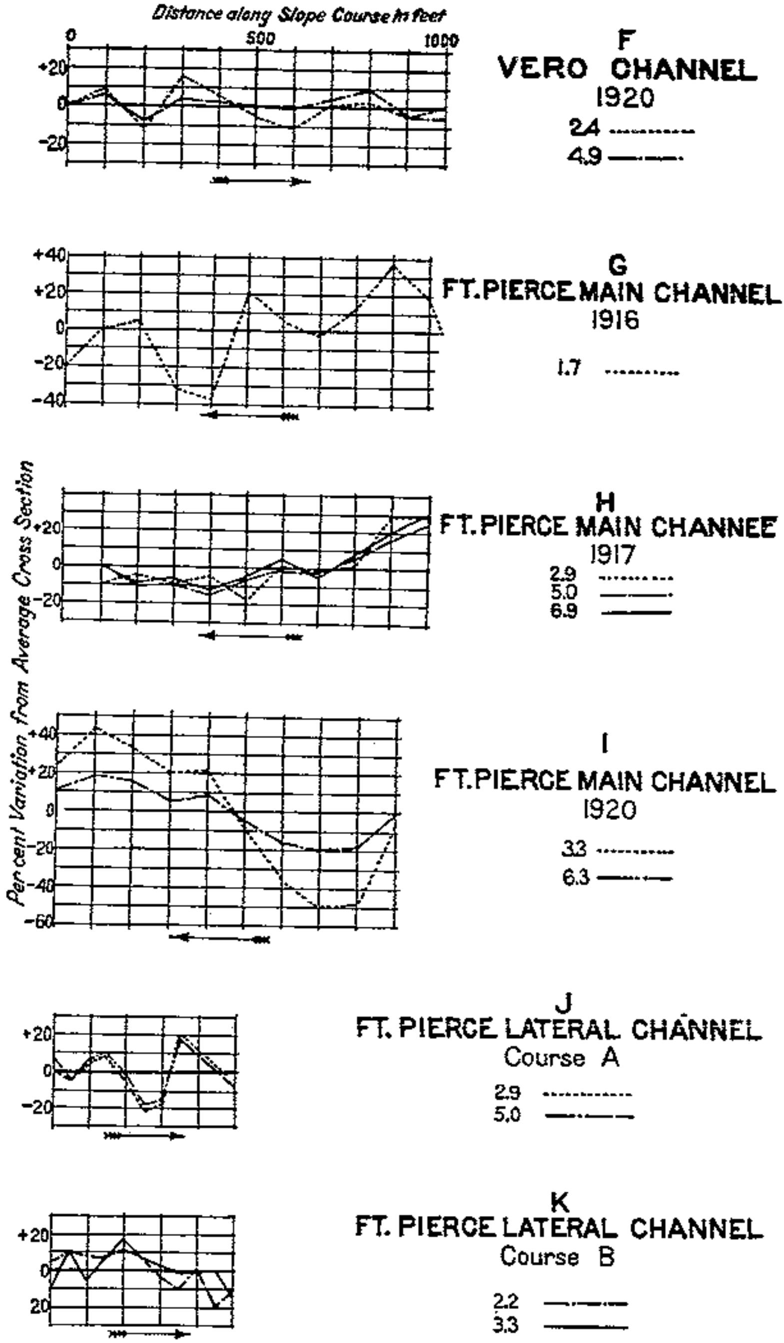


FIGURE 13.—Graphs for experiments in Florida, showing per cent variation



from average cross-sectional area for all cross sections along slope courses

MAIN CHANNEL NEAR FELLSMERE

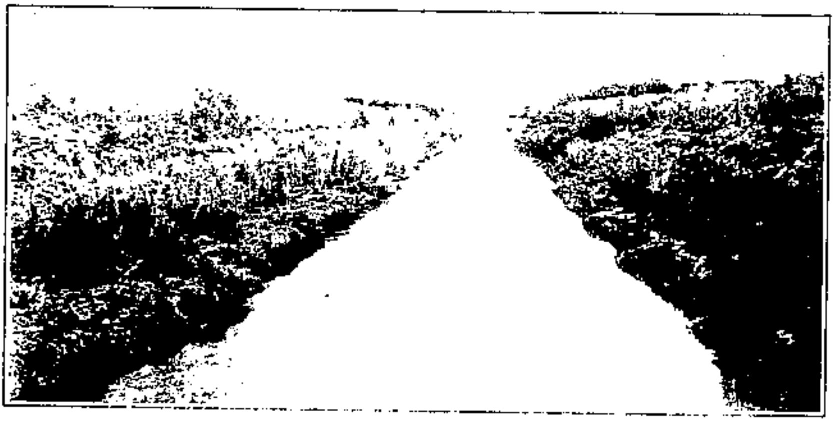
The slope course on this channel was straight and was 2,000 feet long. The gaging station was located about 100 feet below the downstream end of the slope course, which was about 3 miles north of Fellsmere. The gagings were made from a footbridge about 10 feet upstream from the county highway bridge and supported by suspension brackets from the piling of that bridge. The channel in 1916 and 1917 was quite uniform in cross section, there being only one rather abrupt variation, which occurred near the upper end of the course. (Figs. 13, A and 13, B.) The bottom of the channel was broad and regular and quite evenly covered with sand. The side slopes were fairly regular and practically free from vegetation in the lower part of the channel, but rather irregular and covered with vegetation in the upper part. (Fig. 12, A and pl. 15, A.) By 1920 the course had become, on the whole, somewhat more irregular. (Fig. 13, C.)

With the exception of measurement 10, Table 6, for which the highest value of n was obtained, the measurements were made for stages almost wholly in the lower and better part of the channel. For the same part of the channel the values of n obtained during 1917 were somewhat lower than those obtained during 1916. This might be attributed to the fact that the cross section had become somewhat more uniform between the dates of the two sets of measurements, as appears from the graphs shown in Figure 13. The measurements made during 1920 are comparable with those for the lower stages made during 1916 and 1917. The values of n are somewhat higher, due very likely to the fact that the channel contained more vegetation and was more irregular than at the time of the earlier measurements.

MAIN CHANNEL NEAR VERO

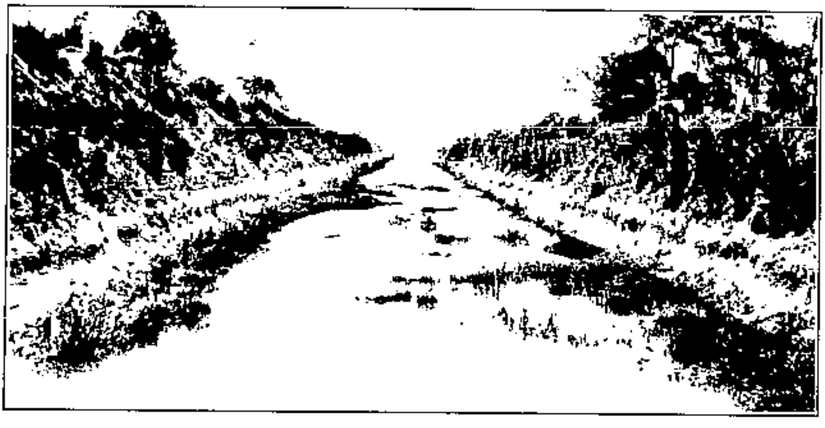
Gagings of this channel were made from a suspension footbridge near Vero. The upper end of the slope course, which was 1,000 feet long, was located about 40 feet downstream from the gaging station. The bottom was sandy, and there were several flat, broad sand bars in the channel during low water. (Pl. 16, A and fig. 12, D.) There was some vegetation in the channel, which can be seen in the view just referred to. The cross-sectional area of the channel was quite uniform except for the lowest measurements, Nos. 16 and 17. (Table 6 and figs. 13, D; 13, E and 13, F.) The side slopes for the three low-stage measurements made during 1916 were fairly regular, but for the three highest stage measurements. Nos. 19, 20, and 24, made at about half-bankful stages, the slopes were quite rough and irregular owing to the fact that large lumps of the bank had sloughed off.

The values of n obtained indicate that the retardation to flow was much greater in the upper part than in the lower part of the channel, which was apparently due to the caving of the banks in the upper part of the channel. On comparing values of n for about similar stages, it is seen that the values obtained during 1920 were somewhat higher than those obtained during 1916 and 1917, which is attributed to the fact that the channel contained more vegetation and was a little more irregular at the later date.



A

B



C

A, Main dredged channel near Fellsmere, Fla.; this view, adjoining the slope course in 1917, represents fairly well the condition of the channel along that course; B, main dredged channel near Fort Pierce, Fla., slope course, 1917; C, same slope course as B above in 1920; channel enlarged by redredging in 1918. (See Table 6)

A

B

C

A, Main dredged channel near Vero, Fla., slope course, 1917; B, lateral dredged channel No. 2, near Fort Pierce, Fla., slope course A, 1917; C, lateral dredged channel No. 2 near Fort Pierce, Fla., slope course B, 1917. (See Table 6)

MAIN CHANNEL NEAR FORT PIERCE

Gagings of this channel were made from a suspension footbridge located about 3 miles west of Fort Pierce. The upper end of the slope course, which was 1,032 feet long, was located about 25 feet downstream from the gaging station. At the time that the measurements were made during 1916 the cross section of the channel was fairly uniform, except for the lowest stage. (Pl. 15, B and figs. 12, G and 13, G). The side slopes were rather irregular. The soil in the bottom of the channel was largely clay, and on the side slopes a very hard clay. There were some water weeds in the bottom of the channel, and a growth of grass and lilies near the water edge at low stage. As would be expected, a high value of n was obtained (Table 6) for the lowest stage, due to the vegetation and to the rough condition and abrupt variations in cross section. The other values were also rather high, due no doubt to the irregularities and vegetation in the channel.

The channel was cleaned out and deepened with a drag-line excavator after the 1916 measurements had been made. After this work had been done, values of n were again determined for the channel during 1917. The upstream end of the 1917 course was located 160 feet farther upstream than that of the 1916 course. The course was straight and was 900 feet long. The cross section of the channel was fairly uniform, there being no very abrupt variations (fig. 13, H), and was in rather good condition except for irregularities in the bottom and some weeds that the excavating machine did not remove. Comparing the values of n obtained during 1917 with those for 1916, it is seen that much lower values were obtained after the channel was cleaned out and deepened.

The same course of channel was used during 1920 as during 1917. It was redredged in 1918, and was both deepened and widened. (Fig. 12, I.) A dense growth of lilies and other vegetation appeared in this channel between 1918 and 1920, which accounts for the extremely high values of n obtained, since measurements were made only for comparatively low stages which were affected by this growth. For higher stages in the channel, no doubt much lower values of n would have been obtained. (Pl. 15, C and fig. 13, I.)

LATERAL DREDGED CHANNEL NO. 2, NEAR FORT PIERCE

Values of n were determined for two courses of this lateral channel, course A being in good condition and course B in very poor condition. The gagings were made from suspension footbridges. A good idea as to the shape, condition, and uniformity of these channels can be obtained from Plates 16, B and 16, C and Figures 12, J; 12, K; 13, J; and 13, K.

Course A was straight and was 503 feet long; it was located at a place where the channel passed through a ridge of hard clay. The side slopes of the channel were probably about as they were left by the excavating machine and showed no evidence of erosion or sloughing off. As may be seen from Plate 16, B, there was some vegetation in the channel. The rather high values of n obtained for this channel were probably due to the presence of vegetation and to the abrupt variations in cross section.

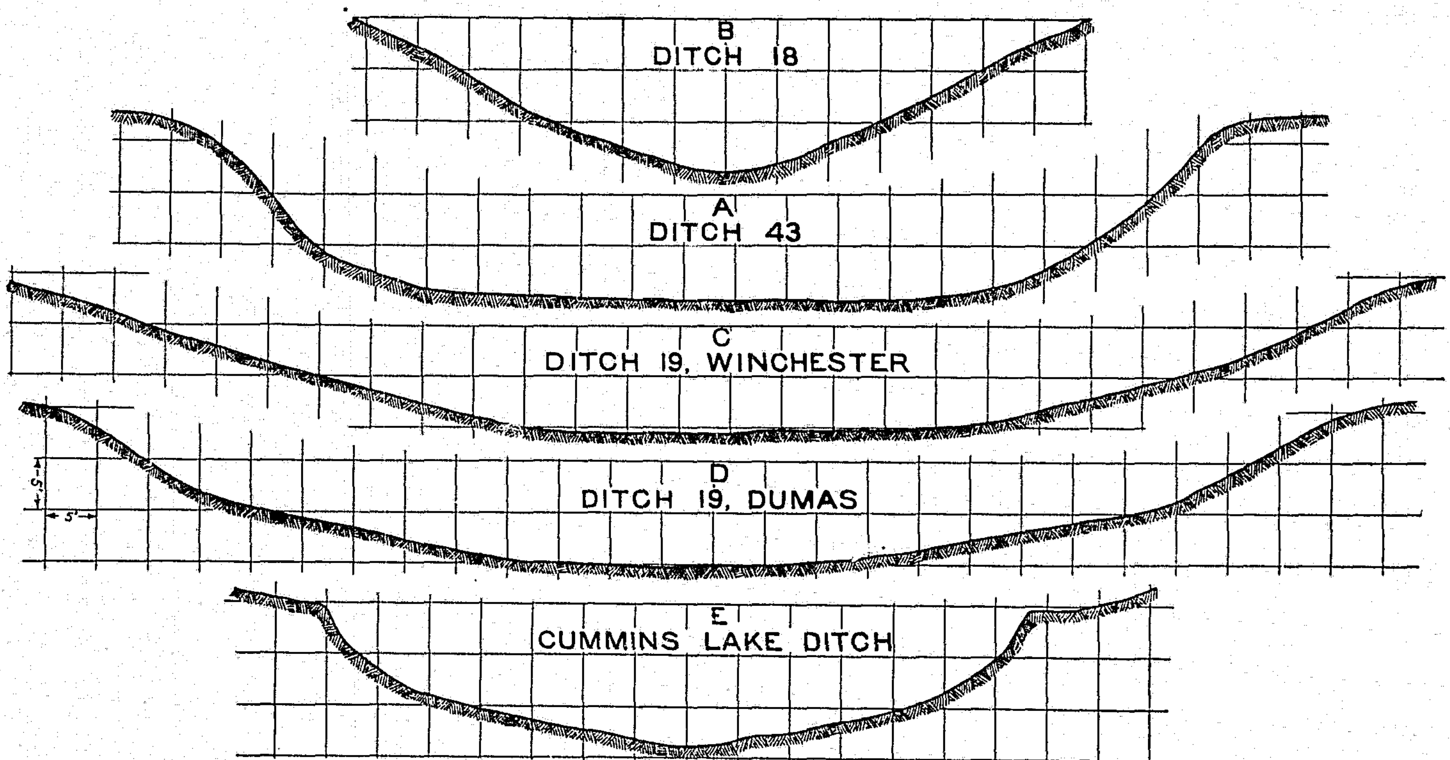


FIGURE 14.—Average cross section of channels for experiments in southeastern Arkansas

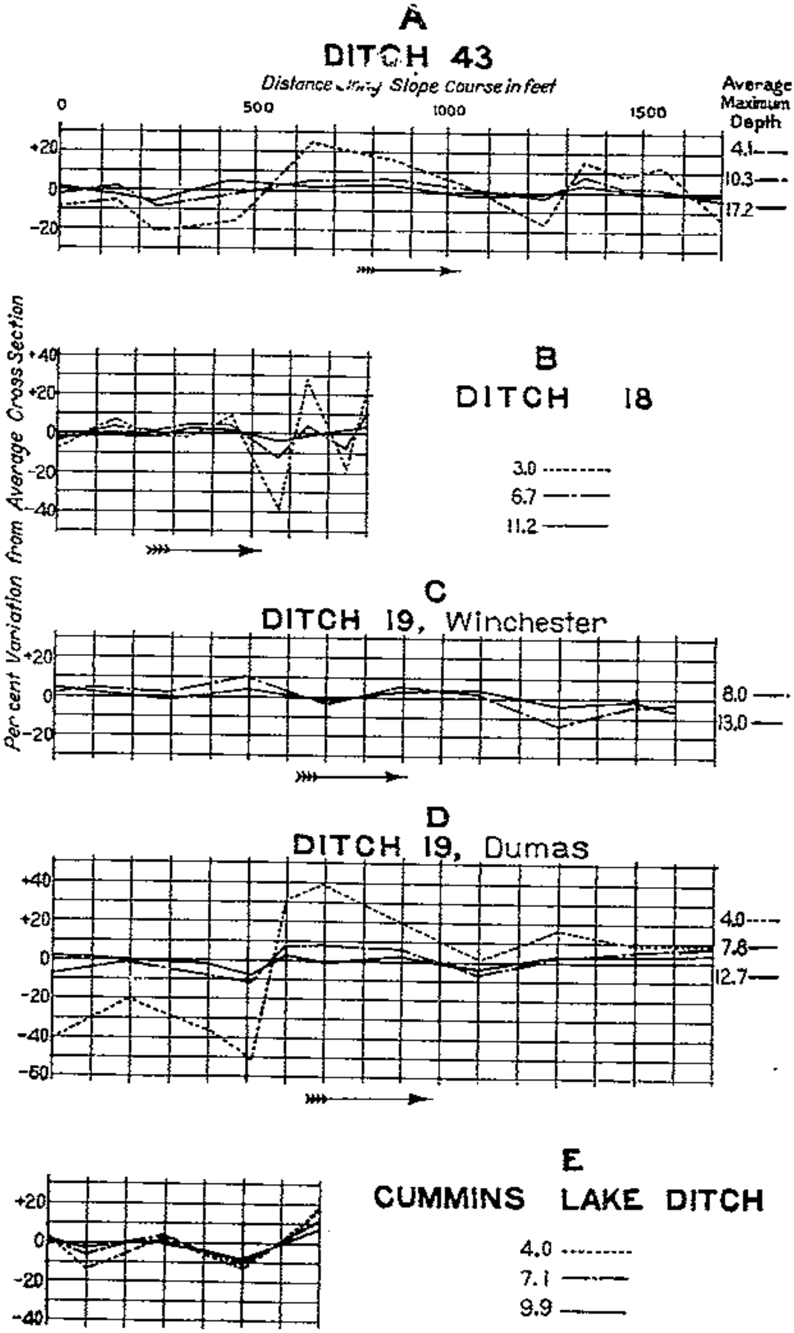


FIGURE 15.—Graphs for experiments in southeastern Arkansas showing per cent variation from average cross-sectional area for all cross sections along slope courses

Course B was straight and was 500 feet in length. This course was located in one of the so-called sand ponds. The soil is sandy and easily eroded. The banks have been washed in, and considerable material had been deposited in the channel. The cross section was very broad and shallow as compared with that for course A. (Fig. 12, K.) There was considerable vegetation, covering the entire perimeter of the channel, as may be seen by referring to Plate 16, C. The values of n obtained are very high, due no doubt principally to the presence of vegetation.

Unusual care was exercised in making the slope measurements and gaugings for both courses of channel. The slope for course A was very small and required precise measurements to secure reliable results.

DISCUSSION OF FLORIDA EXPERIMENTS

Owing to the fact that the slopes for channels in this section of the country are quite small, the velocities are necessarily low. As a result, the channels are subject to silting and to the rapid growth of vegetation. Unless channels in this section are to be carefully maintained, it can be seen from the results of the experiments as given in Table 6 that a comparatively high value of n should be used in their design.

EXPERIMENTS IN EASTERN ARKANSAS

Values of n were determined for the following dredged ditches in eastern Arkansas: Ditch No. 43, ditch No. 18, ditch No. 19 near Winchester, ditch No. 19 near Dumas (all in the Cypress Creek Drainage district), and the Cummins Lake ditch of the Cummins Lake drainage district. The topography of the watersheds of these ditches is comparatively flat. Values of n were determined also for flow through standing timber in St. Francis River floodway, in Poinsett County. This floodway carries the combined flow of St. Francis and Little Rivers. The drainage area of this waterway, although mostly flat, reaches into the hills of the Ozark border in Missouri.

DITCH NO. 43

Measurements on this ditch were made shortly after the dredging of the ditch was finished. The discharge was measured from a pile-trestle highway bridge at right angles to the channel. The slope measurements were made on a straight course 1,710 feet long, just north of the highway bridge on the hard-surfaced road between McGehee and Arkansas City.

A good view of the condition of the channel at the time the measurements were made is shown in Plate 17, A. The channel was in about the same condition as the dredge had left it, there being practically no vegetation in the channel. The bottom and side slopes were somewhat irregular. The cross section of the channel was fairly uniform at high and intermediate stages, but varied considerably for low stages. (Figs. 14, A and 15, A.)

With the exception of measurement No. 5, the values of n obtained for this ditch are close to 0.030. (Table 7.) It is believed that the higher value obtained for measurement No. 5 was due to an error in the measurement of the slope or the discharge.

DITCH NO. 18

Gagings of this ditch were made from a suspension footbridge, a view of which is shown in Plate 17, C. This bridge was located about 300 feet south of the McGehee-Arkansas City highway and about 6 miles west of Arkansas City. The slope course was straight and 810 feet long. The growth in the ditch was cleared out for some distance above and below the gaging station so as to insure accurate current-meter measurements.

This ditch was dredged in June 1918, and the growth of vegetation in the ditch has never been cleared out. The view in Plate 17, B, shows that there were fairly large trees in the channel. This view represents the condition along the slope course during the winter and spring months. Plate 17, C, shows the trees with heavy foliage in the channel and represents the condition during the summer and fall months. The growth in the channel consisted principally of

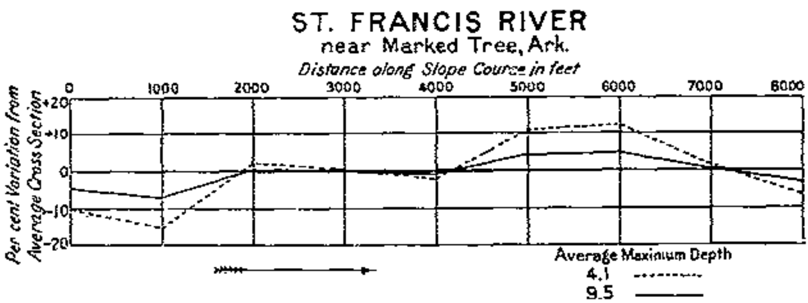


FIGURE 15f.—Graph for experiment on the St. Francis River floodway near Marked Tree, Ark., showing per cent variation from average cross-sectional area for all cross sections along slope course

willow and cottonwood trees. (For cross-section of channel and variation in size, see figs 14, B and 15, B.)

It will be noted in Table 7 that much higher values of n were obtained during the summer and fall when the trees were in full foliage than during the winter and spring; also that values of n were determined for much higher stages during the summer and fall months than during the winter and spring. The highest values of n were obtained for the highest stages of water, which is attributed to the flow encountering more foliage and branches with an increase in stage.

Judging from the values of n obtained for ditch No. 43, the capacity of ditch No. 18 for the condition shown in Plate 17, C, is only about one-fourth of what it would be if the drain were kept cleared.

TABLE 7.—*Results of experiments in eastern Arkansas*

DITCH NO. 43 NEAR ARKANSAS CITY, ARK.

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
		Feet	*Feet*	*Second-feet*	*Sq. ft.*	*Ft. per sec.*	*Feet*				
1	May 3, 1926	4.1	68.2	150.7	206.5	0.73	2.92	0.0000630	53.8	0.032	*Course*, straight; 1,710 feet long. *Cross section*, not much variation in shape; for variation in size, see fig. 15, A. *Side slopes*, somewhat irregular. *Bottom*, rather irregular and uneven. *Soil*, heavy silty clay. *Condition*, practically no vegetation or obstructions in channel; newly dredged. *Constructed*, September, 1924. (Pl. 17, A and fig. 14, A.)
2	Feb. 19, 1926	4.7	70.4	250.1	250.6	1.00	3.42	.0000807	60.2	.030	
3	May 11, 1926	6.0	74.4	371.2	336.2	1.10	4.34	.0000708	62.8	.031	
4	Mar. 7, 1926	9.9	85.0	1,178.2	660.0	1.78	7.18	.0000824	73.2	.030	
5	Jan. 26, 1926	10.1	85.1	900.6	670.2	1.34	7.27	.0000555	66.7	.034	
6	Jan. 23, 1926	10.3	86.0	1,401.2	693.9	2.02	7.47	.0001000	73.9	.030	
7	Mar. 7, 1926	10.9	87.1	1,648.7	743.0	2.22	7.87	.0000988	79.6	.028	
8	Mar. 9, 1926	11.2	87.7	1,374.0	766.3	1.79	8.06	.0000707	75.0	.031	
9	Dec. 16, 1925	12.6	90.4	1,788.5	896.9	1.99	8.99	.0000737	77.3	.030	
10	Nov. 5, 1925	16.2	98.6	3,460.8	1,255.9	2.75	11.27	.0000988	82.4	.029	
11	Nov. 13, 1925	16.8	99.7	3,063.1	1,314.3	2.33	11.61	.0000649	84.9	.029	
12	Nov. 9, 1925	17.2	100.8	3,386.5	1,348.0	2.51	11.77	.0000792	82.2	.030	
13	Nov. 10, 1925	17.2	100.8	3,407.5	1,346.7	2.53	11.76	.0000830	81.0	.030	
	----------	[1] 18.0	----------	----------	----------	----------	----------	----------	----------	----------	

DITCH NO. 18 NEAR McGEHEE, ARK., DURING WINTER AND SPRING MONTHS

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
14	Feb. 21, 1925	3.0	22.7	22.0	46.5	0.47	1.91	0.000124	30.5	0.049	*Course*, straight; 810 feet long. *Cross section*, quite uniform in shape; for variation in size, see fig. 15, B. *Side slopes*, irregular and uneven. *Bottom*, irregular and uneven. *Soil*, heavy silty clay. *Condition*, practically entire section filled with large sized growth of trees consisting principally of willows and cottonwoods. *Constructed*, June, 1918. (Pl. 17, B and fig. 14, B.)
15	Mar. 15, 1925	4.5	30.4	55.2	85.0	.65	2.61	.000151	32.8	.051	
16	Feb. 19, 1926	4.7	31.4	61.1	93.0	.66	2.75	.000104	39.1	.044	
17	Mar. 22, 1926	5.5	34.4	86.7	118.0	.73	3.21	.000116	37.8	.048	
18	Jan. 23, 1926	6.5	39.3	125.1	156.7	.80	3.70	.000152	33.8	.056	
19	Jan. 27, 1926	6.7	40.1	108.6	162.5	.67	3.75	.000109	33.2	.057	
20	Mar. 17, 1925	7.8	44.5	230.6	214.5	1.08	4.42	.000317	28.9	.069	
21	Dec. 17, 1925	8.1	45.5	170.7	225.5	.75	4.55	.000179	26.3	.077	
22	Dec. 15, 1925	8.9	48.7	216.4	266.0	.81	4.99	.000290	21.3	.099	

DITCH NO. 18 NEAR McGEHEE, ARK., DURING SUMMER AND FALL MONTHS

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
23	May 3, 1926	5.7	36.0	88.5	127.0	0.70	3.28	0.000128	34.1	0.053	*Course*, same as above. *Condition*, practically the same except that all growth is in full leaf; very dense foliage. (Pl. 17, C.)
24	Nov. 4, 1925	6.1	37.6	88.2	140.5	.63	3.47	.000218	22.9	.081	
25	May 11, 1926	8.0	45.0	160.6	221.0	.77	4.48	.000188	26.6	.076	
26	Nov. 12, 1925	10.0	52.1	183.6	321.5	.57	5.60	.000203	16.9	.132	
27	Nov. 6, 1925	10.7	53.7	282.1	353.6	.80	5.91	.000290	19.3	.117	
28	Nov. 9, 1925	11.0	54.9	212.0	371.3	.57	6.08	.000168	17.8	.130	
29	Nov. 5, 1925	11.2	55.4	228.9	384.8	.59	6.23	.000179	17.7	.132	

DITCH NO. 19 NEAR WINCHESTER, ARK.

30	May 13, 1925	8.0	98.9	447.1	548.5	0.82	5.39	0.0000281	66.6	0.032	*Course*, straight; 1,600, feet long. *Cross section*, some variation in shape; for variation in size, see fig. 15, C. *Side slopes*, irregular. *Bottom*, rather irregular. *Soil*, upper, clay and sandy loam; lower, silty clay. *Condition*, some silting in channel; thick growth of willows and cottonwood trees cover most of left bank and about half of right bank; very little undergrowth, due to pasturing; grass on slopes; lower part of channel comparatively free from vegetation, except for some willows on small islands near upper end of course. *Constructed*, February, 1918. (Pl. 18, A and fig. 14, C.)
31	May 12, 1925	8.3	100.2	686.3	577.6	1.10	5.60	.0000507	65.1	.033	
32	Jan. 23, 1926	11.7	116.2	1,385.5	949.7	1.46	7.84	.0000937	53.9	.043	
33	Jan. 25, 1926	11.7	116.3	1,454.1	951.6	1.53	7.85	.0000944	56.2	.041	
34	Nov. 8, 1925	13.0	124.9	1,536.2	1,110.9	1.38	8.52	.0000962	48.2	.050	
		[1] 16.0									

DITCH NO. 19 NEAR DUMAS, ARK.

35	Oct. 14, 1925	4.0	67.4	115.1	170.5	0.68	2.48	0.0002106	29.8	0.055	*Course*, straight; 1,700 feet long. *Cross section*, fairly uniform in shape with exception of one cross section at sand bar and one due to ridge in center of channel; for variation in size, see fig. 15, D. *Side slopes*, somewhat irregular. *Bottom*, uneven and irregular. *Soil*, upper, clay and sandy loam; lower, silty clay. *Condition*, short Bermuda grass on sides of channel; pastured; very few willows, weeds, or bushes in channel. *Constructed*, December, 1914. (Pl. 21, A and fig. 14, D.)
36	May 12, 1925	7.1	95.8	541.0	433.0	1.25	4.40	.0001112	56.5	.035	
37	May 11, 1925	7.8	99.3	790.9	496.9	1.59	4.86	.0001476	59.4	.034	
38	Oct. 18, 1925	9.7	106.6	784.1	686.0	1.14	6.21	.0000588	59.7	.037	
39	Dec. 15, 1925	11.0	111.2	1,151.0	832.3	1.38	7.19	.0000553	69.2	.033	
40	Jan. 22, 1925	11.6	112.9	1,512.7	894.6	1.69	7.59	.0000788	69.1	.033	
41	Nov. 7, 1925	12.7	115.7	1,805.5	1,018.4	1.77	8.37	.0000894	64.7	.036	
		[1] 13.5									

CUMMINS LAKE DITCH NEAR GOULD, ARK., DURING WINTER AND SPRING MONTHS

42	Feb. 18, 1926	4.2	44.1	128.5	115.8	1.11	2.51	0.000574	29.2	0.057	*Course*, straight; 710 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 15, E. *Side slopes*, fairly regular. *Bottom*, fairly regular. *Soil*, upper, sandy loam; lower, silty clay. *Condition*, growth of willows in channel 6 to 10 feet high except on upper part of side slopes and narrow strip of channel, willows about one year old. *Constructed* summer 1924 (Pl. 18, B and fig. 14, E.
43	Apr. 24, 1926	5.0	49.2	200.7	154.8	1.30	3.02	.000473	34.4	.051	
44	Dec. 14, 1926	6.0	53.7	245.9	202.0	1.22	3.61	.000448	30.3	.062	
45	Jan. 22, 1926	9.2	63.1	579.4	390.4	1.43	5.78	.000284	36.5	.059	
46	Jan. 21, 1926	9.9	64.3	764.1	432.8	1.77	6.22	.000304	40.7	.053	
47	do	9.9	64.3	787.4	433.5	1.82	6.23	.000309	41.5	.052	

CUMMINS LAKE DITCH NEAR GOULD, ARK., DURING SUMMER AND FALL MONTHS

48	May 12, 1926	4.0	41.8	55.9	104.5	0.53	2.41	0.000273	20.7	0.078	*Course*, same as above. *Condition*, practically the same, except that willows and other vegetation are in full foliage. (Pl. 18, C.)
49	Nov. 11, 1926	7.1	57.8	314.1	262.6	1.20	4.34	.000390	29.2	.068	
50	Nov. 7, 1926	8.4	61.1	410.7	338.8	1.21	5.22	.000315	20.9	.070	
		[1] 13.5									

[1] Average maximum depth at bankful stage.

TABLE 7.—*Results of experiments in eastern Arkansas*—Continued

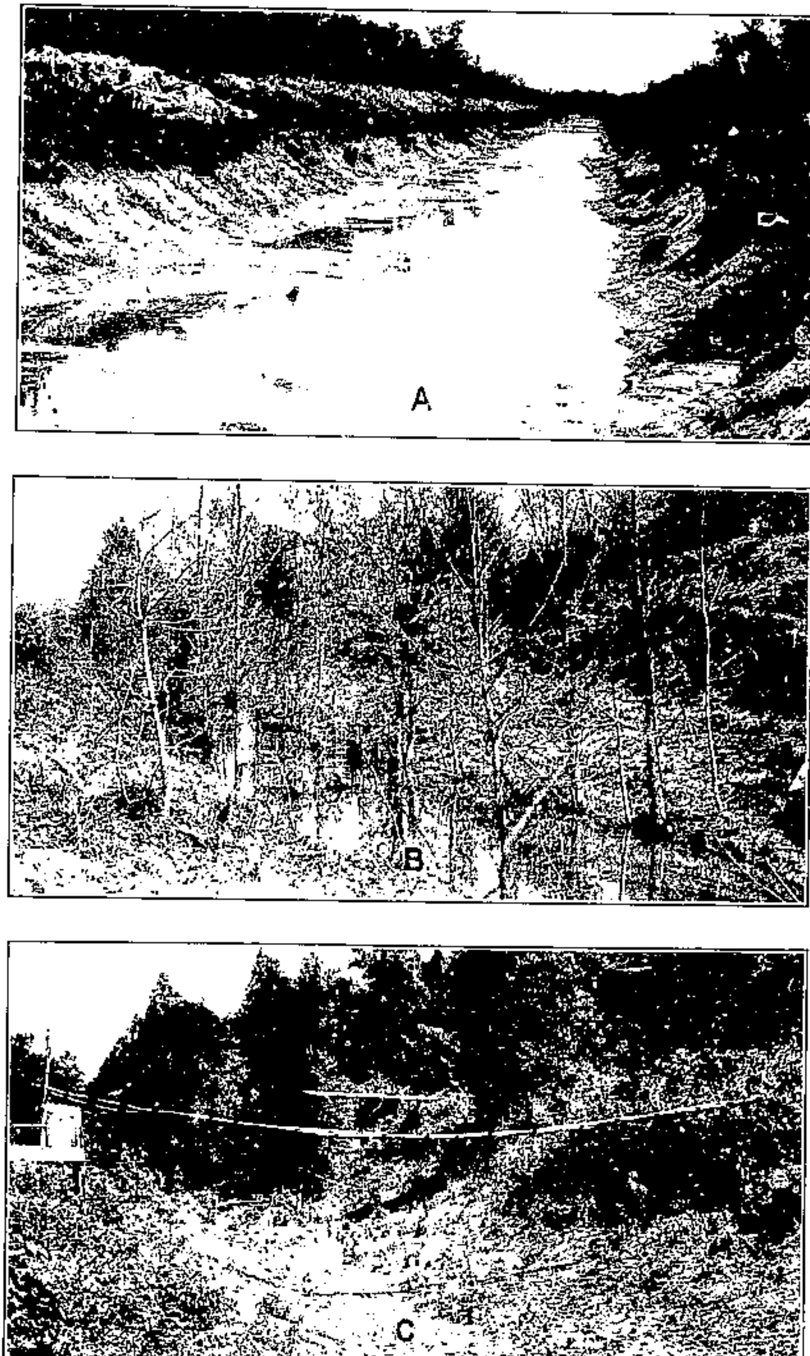
ST. FRANCIS RIVER FLOOD WAY NEAR MARKED TREE, ARK., DURING WINTER MONTHS

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
		Feet	*Feet*	*Second-feet*	*Sq. ft.*	*Ft. per sec.*	*Feet*				
51	Mar. 13, 1927	4.08	2,000	3,528	8,152	0.433	4.08	0.0001061	20.8	0.095	*Course*, straight; 8,000 feet long. *Cross section*, variation in depth only; for variation in size, see fig. 15, F. *Side slopes*, none. *Bottom*, fairly even and regular, with occasional flat-bottom sloughs. *Soil*, varies from medium fine sand on low broad ridges to fine clay in depressed areas. *Condition*, practically virgin timber, principally oak, gum, and cypress; very little undergrowth except occasional dense patches of bushes and small trees; some logs and dead fallen trees; *Constructed* about 1922. (Pls. 19 and 20.)
52	Mar. 10, 1927	4.16	2,000	3,901	8,312	.469	4.16	.0001042	22.5	[2] .088	
53	Mar. 9, 1927	4.41	2,000	4,126	8,828	.467	4.41	.0001036	21.8	[2] .093	
54	Mar. 8, 1927	4.57	2,000	4,059	9,134	.444	4.57	.0001056	20.2	.102	
55	Mar. 6, 1927	4.97	2,000	4,613	9,932	.464	4.97	.0001042	20.4	.104	
56	Feb. 25, 1927	6.76	2,000	7,383	13,522	.546	6.76	.0001030	20.7	.116	
57	Feb. 23, 1927	7.07	2,000	8,205	14,134	.581	7.07	.0001030	21.5	[2] .114	
58	Feb. 22, 1927	7.19	2,000	7,751	14,384	.539	7.19	.0001029	19.8	.125	
59	Feb. 21, 1927	7.34	2,000	8,368	14,688	.570	7.34	.0001028	20.8	[2] .120	
60	Feb. 20, 1927	7.48	2,000	8,707	14,968	.582	7.48	.0001054	20.7	[2] .121	
61	Feb. 18, 1927	7.77	2,000	8,907	15,540	.573	7.77	.0001050	20.1	[2] .127	
62	Feb. 17, 1927	7.86	2,000	8,650	15,710	.551	7.86	.0001049	19.2	.134	
63	Jan. 31, 1927	8.88	2,000	10,648	17,752	.600	8.88	.0001227	18.2	.149	
64	Feb. 4, 1927	9.40	2,000	11,434	18,808	.608	9.40	.0001146	18.5	.150	
65	Feb. 2, 1927	9.46	2,000	11,748	18,918	.621	9.46	.0001215	18.3	.152	

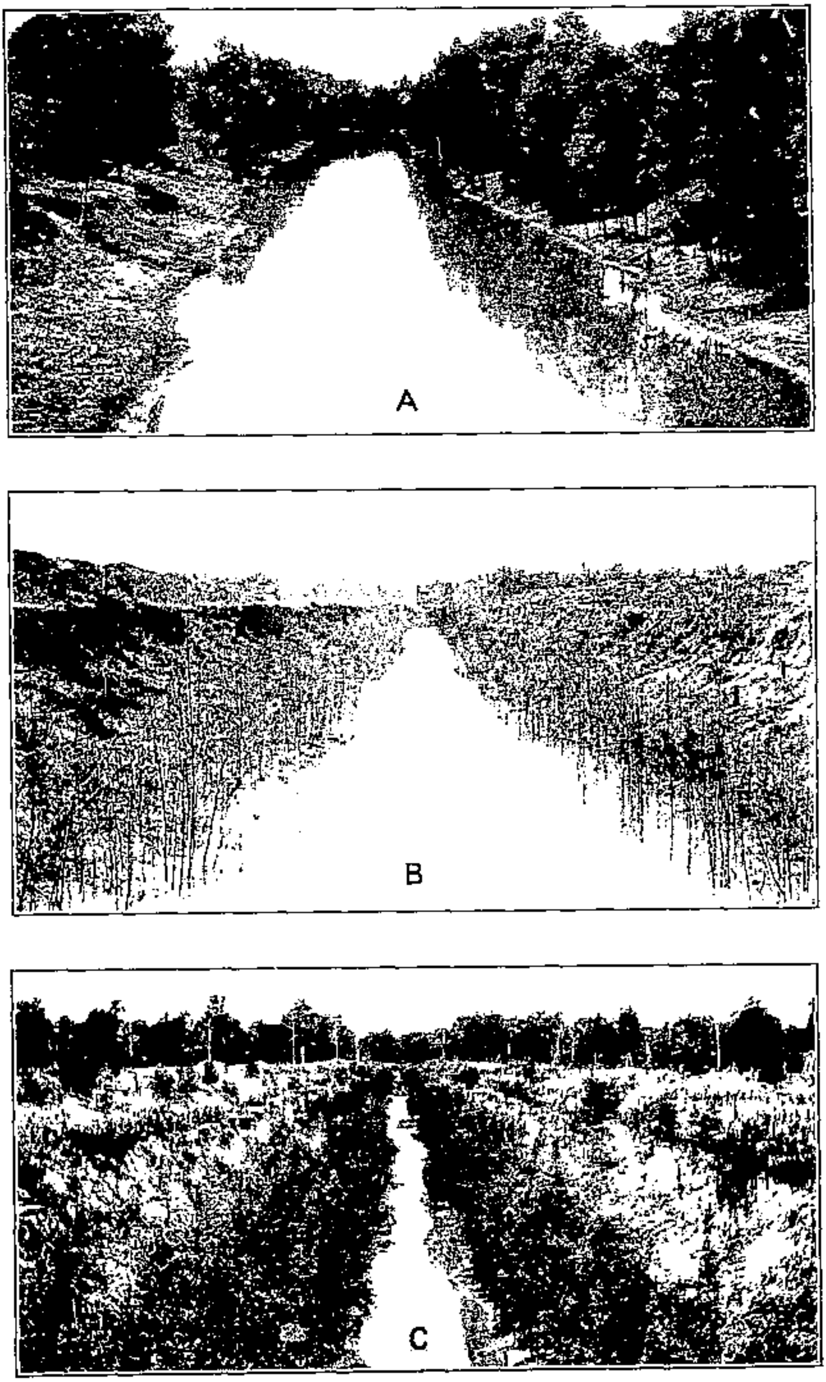
ST. FRANCIS RIVER FLOOD WAY NEAR MARKED TREE, ARK., DURING SUMMER MONTHS

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
66	July 17, 1928	8.89	2,000	12,298	17,788	0.691	8.89	0.0001255	20.7	0.129	*Course*, same as above. *Condition*, trees in full foliage, but there appeared to be little foliage below maximum elevation of water during these measurements.
67	July 16, 1928	9.10	2,000	12,772	18,190	.702	9.10	.0001281	20.6	.131	
68	July 15, 1928	9.31	2,000	13,112	18,624	.704	9.31	.0001294	20.3	.134	
69	July 1, 1928	9.95	2,000	13,862	19,894	.697	9.95	.0001246	19.8	.142	
70	July 3, 1928	10.18	2,000	14,589	20,366	.716	10.18	.0001270	19.9	.142	
71	July 4, 1928	10.28	2,000	14,393	20,554	.700	10.28	.0001288	19.2	.148	
72	July 5, 1928	10.34	2,000	14,568	20,678	.705	10.34	.0001313	19.1	.150	
73	July 7, 1928	10.34	2,000	14,496	20,678	.701	10.[illegible]	.0001323	19.0	.150	
74	July 6, 1928	10.36	2,000	14,467	20,710	.699	10.36	.0001326	18.9	.152	

[2] Based on measurements of surface velocity only.



A, Dredged Ditch No. 43 of Cypress Creek drainage district, near Arkansas City, Ark., looking up slope course, July, 1926; B, dredged Ditch No. 18 of Cypress Creek drainage district, near Arkansas City, Ark., looking down slope course, March, 1925; C, same slope course as B, above, looking downstream, showing growth and heavy foliage in June, 1926. (See Table 7)



A, Ditch No. 19 of Cypress Creek drainage district, near Winchester, Ark., looking up slope course, July, 1926; B, Cummins Lake dredged channel, near Gould, Ark., looking up slope course, March, 1926; C, same view as B, above, showing foliage on willows in June, 1926. (See Table 7)

DITCH NO. 19 NEAR WINCHESTER

Gagings of this ditch were made from a pile-trestle highway bridge about 2 miles east of Winchester, Ark. The gauging section was not a very good one, and the discharge measurements are not as accurate as those made from single-span bridges such as was used on ditch No. 18. The slope course was straight and 1,600 feet long. The channel was pastured, so there were practically no weeds or long grass on the slopes, and the lower foliage was eaten off of the trees by stock. As can be seen from the view in Plate 18, A, the lower part of the channel is quite free from vegetation of any sort. Most of the left bank was covered with trees and about half of the right bank. There was also a small island about 25 feet wide and 150 feet long covered with a growth of willows near the upper end of the slope course. The variation in size of the cross section of the channel was not large. (Figs. 14, C and 15, C.)

It can be seen from Table 7 that comparatively low values of n were obtained for the lower part of the channel. The value of n increased when the water reached the lower part of the trunks of the trees on the banks and was highest when the water reached the foliage and branches.

DITCH NO. 19 NEAR DUMAS

A single-span steel bridge was used in gaging the flow in this ditch about 2 miles east of Dumas, Ark. The slope course was straight and 1,700 feet in length. The channel was pastured close and contained very little vegetation. (Pl. 21, A.) The side slopes and bottom of the lower part of the channel were quite irregular, which accounts for the high value of n obtained for the lowest stages. There was also considerable variation in the size of the cross section for low stages. (Figs. 14, D and 15, D.) The channel was fairly uniform for higher stages, with the exception of one short stretch where there was a small sand bar and another where there was a narrow ridge in the center of the channel. It will be seen from Table 7 that the values of n for stages ranging from medium to bankful are fairly consistent, the differences being due, it is believed, to irregularities in the channel.

CUMMINS LAKE DITCH

Gagings of this channel were made from a single-span wooden truss bridge about 4 miles north of Gould, Ark. The slope was measured on a straight course 710 feet long, just above the bridge. (See figs. 14, E and 15, E for average cross section and variation in area.) Two views of the channel are shown in Plate 18, one taken in March, 1926, and the other about three months later. The earlier view shows a thick growth of willows, about 1 year old at the time, almost completely filling the ditch outside of the low-water channel. The later view shows the willows in full leaf.

Table 7 shows that the values of n were appreciably larger when the willows were in full leaf than before the foliage appeared. These results clearly show what effect a short-time growth of willows has upon the hydraulic efficiency of a drainage ditch. The capacity of this ditch when first dredged was about 50 per cent greater than for the condition shown in Plate 18, B, and about 100 per cent greater than for the condition shown in Plate 18, C.

ST. FRANCIS RIVER FLOOD WAY

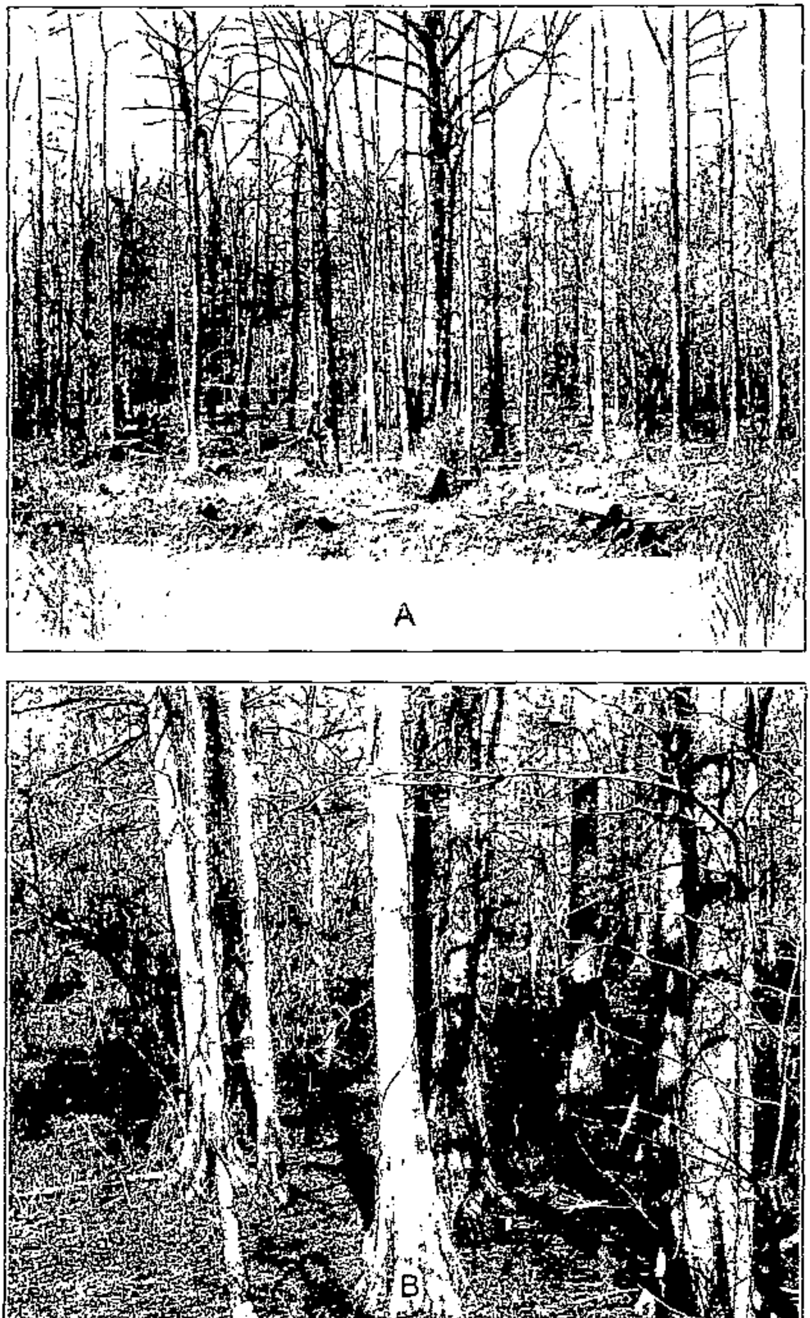
These experiments were made on a straight course of the flood way 8,000 feet long, about 4 miles northwest of Marked Tree, Ark. The flood way lies between parallel levees that are about 2,500 feet apart. Along the flood way side of each levee is an open channel about 70 feet in top width and 11 feet in depth. (Fig. 16.) To eliminate the effect of the higher velocities in the channels, computations were made for only 2,000 feet width of flow, between lines about 250 feet from either levee.

Between the open channels the flood way is covered with a practically virgin growth of oak, gum, cypress, cottonwood, and other trees. Except for occasional dense patches of small trees and bushes, the course was almost free from undergrowth, but there were logs and dead fallen trees scattered throughout the flood way. Four typical views are shown in Plates 19 and 20. The bottom of the course was fairly even and regular, with occasional flat-bottom sloughs; but there was considerable variation in average depth and cross-sectional area, as determined by cross sections measured at 1,000-foot intervals. (Fig. 15, F.)

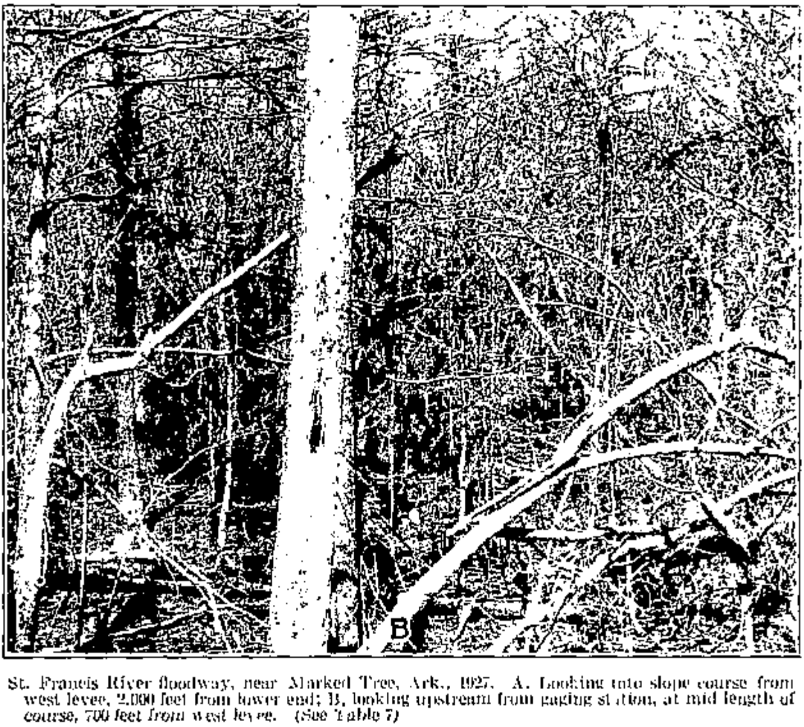
The discharge measurements were made from the Chapman & Dewey Lumber Co.'s railroad trestle, midway between the ends of the course. It was thought this would determine the average flow through the course more nearly than gagings at any other single cross section, for there was some flow back and forth between the timbered area and the open channels. The velocity of the water was measured by current meter, at 50-foot intervals across the flood way. For 7 of the 15 gagings in 1927, the measurements were made at top, middle, and bottom depths (Nos. 51, 55, 58, and 62 to 65 in Table 7); for 6 gagings, at the surface only (Nos. 52, 53, 57, 59, 60 and 61); and for 2 gagings, a combination of the surface and the three-point measurements was used (Nos. 54 and 56). The coefficients used for computing mean velocity from surface velocity in each vertical were obtained from the three-point gagings. The values of n obtained from three-point gagings and from the combination of three-point and surface gagings are more dependable than those from surface gagings only (indicated by footnote in Table 7). All the gagings in 1928 were made by the three-point method. The slope of the water surface was determined from careful measurements on the east side of the flood way.

The values from the more dependable gagings in 1927 show a continuous increase with depth of flow, from 0.095 to 0.152; the values from surface gagings are somewhat lower, but likewise show a continuous increase of n with depth of flow. This variation in the value of n is attributed to the greater number of the branches of trees encountered by the flow at the higher stages. The measurements in 1928 were made in the summer when the timber in the flood way was in full leaf, whereas the earlier measurements were made under winter conditions. The depths ranged from 0.6 foot below to 0.9 foot above the maximum for the 1927 measurements. The values obtained for n range from 0.129 to 0.152, increasing with the depth of flow as was found for the winter measurements. For similar depths, however, the values obtained in 1928 are slightly lower than those obtained in 1927.

When the water subsided after the 1928 measurements, an examination showed that there was very little foliage below the point of



St. Francis River floodway, near Marked Tree, Ark., 1927. A, looking into slope course from east levee, 2,000 feet from upper end; B, looking upstream from gaging station, at mid length of course, 600 feet from east levee. (See Table 7)



St. Francis River floodway, near Marked Tree, Ark., 1927. A, Looking into slope course from west levee, 2,000 feet from lower end; B, looking upstream from gaging station, at mid length of course, 700 feet from west levee. (See Table 7) maximum depth of flow during the measurements, owing to the dense shade afforded by the trees. Therefore no appreciable difference in the values of n obtained for the winter and summer measurements would be expected. The difference between the values given for n by the two sets of gagings probably is due to a difference in making the measurements of bottom velocity. The 1927 determinations showed the bottom velocities to be remarkably low as compared with the velocities at mid-depth, due to considerable vegetation on the bottom of the flood way at and above the gaging station. The same condition existed in 1928, but an appreciable increase in velocity was shown when the meter was raised but slightly above the bottom. In the later set of measurements, the meter was thus raised because it was believed that the velocities obtained were more representative.

It appears that the value of n for high stages could be reduced appreciably by cutting off the tree branches that are submerged by the deepest water. A further reduction in n could be made by clearing the undergrowth, logs, and fallen trees from the flood way. If n were reduced to 0.046, as found for the higher stages in the cleared course of the main diversion flood way in Little River drainage district, Missouri (Table 8), by clearing off the timber, undergrowth, and débris, it appears that the capacity of St. Francis River flood way could be nearly tripled.

DISCUSSION OF ARKANSAS EXPERIMENTS

The results of the experiments conducted on ditch No. 18 and the Cummins Lake ditch indicate clearly the effect of growth of vegetation upon the hydraulic efficiency of a drainage ditch, both long-time growth as for ditch No. 18, and short-time growth as for the Cummins Lake ditch. These results emphasize the importance and necessity of systematically maintaining ditches in this locality.

The values of n obtained for ditch No. 43 show what can be expected when ditches are kept in good condition. Annual clearing is required to keep a ditch in fairly good condition in this locality, and even then considerable vegetation will appear in the ditch during the summer months. It is therefore believed not advisable to use a value of n lower than 0.035 in planning ditches in this section of Arkansas, and in areas with similar characteristics in other States. Where systematic maintenance is not intended, much larger values of n should be used.

The values of n found for St. Francis River flood way are about one-third greater than those determined about five years earlier for the uncleared course of flood way in Little River drainage district. (Table 8.) Physical conditions on the former course appear fairly typical for virgin timber on the bottom lands in this section of the Mississippi Valley, but many more experiments are necessary, on other courses, to indicate average values or a range of values of n for such lands.

EXPERIMENTS IN SOUTHEASTERN MISSOURI

These experiments were conducted on the following channels in the Little River drainage district: Main diversion flood way, excavated channel in main diversion flood way, ditch No. 1, and Sals Creek rock channel. The topography of the watershed of ditch No. 1 is comparatively flat, while for the other channels it is quite hilly.

TABLE 8.—*Results of experiments in southeastern Missouri*

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
MAIN DIVERSION FLOOD WAY NEAR NASH, MO., CLEARED COURSE											
		Feet	*Feet*	*Second-feet*	*Sq. ft.*	*Ft. per sec.*	*Feet*				
1	Apr. 6, 1922	2.8	823.4	905.0	2,292.6	0.395	2.78	0.0000516	32.9	0.052	*Course*, straight, 3,000 feet long. *Cross section*, no variation in shape; for variation in size, see figure 18, A. *Side slopes*, quite uniform on levee side. *Bottom*, fairly even and regular. *Soil*, heavy dark clay or gumbo. *Condition*, numerous stumps, but just cleared of all brush and sprouts; very little vegetation. *Constructed*, 1916. (Pl. 22, A and fig. 17, A.)
2	Apr. 4, 1922	4.4	826.6	2,242.6	3,579.7	.626	4.33	.0000506	42.4	.047	
3	Apr. 3, 1922	5.0	828.1	3,141.4	4,101.0	.766	4.95	.0000540	46.9	.044	
4	Apr. 1, 1922	5.2	828.8	4,137.0	4,322.6	.957	5.21	.0000843	45.6	.046	
5	Apr. 2, 1922	5.5	829.7	4,077.5	4,540.9	.898	5.47	.0000696	46.0	.046	
MAIN DIVERSION FLOOD WAY NEAR NASH, MO., UNCLEARED COURSE											
6	Apr. 3, 1922	4.5	824.8	1,874.8	3,682.0	.509	4.46	0.0000798	27.0	0.075	*Course*, straight; 3,000 feet long. *Cross section*, no variation in shape; for variation in size, see figure 18, B. *Side slopes*, quite uniform on levee side. *Bottom*, fairly even and regular. *Soil*, heavy dark clay or gumbo. *Condition*, about 3 or 4 years' growth of willows and sprouts from stumps, very few weeds and vines, some logs and drift; stumps about the same as in cleared flood way. *Constructed*, 1916. (Pl. 22, B and fig. 17, B.).
7	Apr. 1, 1922	4.5	824.9	2,672.3	3,697.9	.723	4.48	.0001592	27.1	.075	
8	Apr. 2, 1922	4.9	829.7	2,631.1	4,004.1	.657	4.84	.0001233	26.9	.077	
EXCAVATED CHANNEL IN MAIN DIVERSION FLOOD WAY NEAR NASH, MO.											
9	Apr. 7, 1922	22.7	144.6	4,778	2,316	2.06	14.81	0.0000470	78.1	0.036	*Course*, straight; 3,000 feet long. *Cross section*, some variation in shape; for variation in size, see figure 18, C. *Side slopes*, upper half of course, very irregular; lower half, left side very irregular; right side paved with rock on 2½ to 1 slope. *Bottom*, irregular. *Soil*, principally heavy dark clay or gumbo, lower part of channel sandy. *Condition*, practically no vegetation in channel, erosion very active. *Constructed*, 1916. (Pl. 23, A and fig. 17, C.)
10	Apr. 6, 1922	23.3	144.6	5,117	2,400	2.13	15.35	.0000503	76.6	.037	
11	Apr. 4, 1922	24.8	144.6	6,356	2,617	2.43	16.73	.0000540	80.8	.035	
12	Apr. 3, 1922	25.5	144.6	7,103	2,715	2.62	17.36	.0000570	83.3	.034	
13	Apr. 1, 1922	25.9	144.6	9,020	2,780	3.24	17.77	.0000893	81.3	.033	
14	Apr. 2, 1922	26.0	144.6	8,213	2,793	2.94	17.86	.0000723	81.8	.034	
		[1] 20.5									

DITCH NO. 1 NEAR CHAFFEE, MO., BEFORE GROWTH OF WILLOWS

15	Jan. 26, 1923	3.2	17.7	26.6	39.0	0.68	2.00	0.000058	63.1	0.025	*Course*, straight; 800 feet long. *Cross section*, very little variation in shape; for variation in size, see figure 18, D. *Side slopes*, quite regular. *Bottom*, fairly regular. *Soil*, dark, heavy, tenacious clay. *Condition*, newly cleared channel, practically no vegetation. *Constructed*, December, 1914. (Pl. 21, B and fig. 17, D.)
16	Jan. 25, 1923	3.5	18.4	34.9	45.1	.77	2.18	.000070	62.3	.026	
17	Mar. 6, 1923	3.8	19.2	43.9	50.7	.87	2.34	.000086	61.4	.027	
18	Jan. 24, 1923	4.5	21.0	57.9	62.6	.92	2.64	.000080	63.3	.027	
19	Apr. 13, 1923	5.2	23.2	91.6	78.8	1.16	3.01	.000108	64.4	.028	
20	Jan. 23, 1923	5.8	25.2	91.9	93.8	.98	3.28	.000060	65.2	.028	
21	Jan. 31, 1923	6.4	26.7	140.9	107.8	1.31	3.67	.000110	65.2	.029	
22	Mar. 13, 1923	6.8	28.2	148.2	121.6	1.22	3.77	.000096	64.1	.029	
23	Feb. 3, 1923	7.6	30.2	184.2	143.3	1.29	4.06	.000109	61.3	.031	
24	Jan. 22, 1923	7.7	30.4	182.1	146.3	1.24	4.10	.000099	61.5	.031	
25	Mar. 12, 1923	7.8	30.5	220.1	148.2	1.49	4.13	.000144	61.1	.031	
26	Feb. 1, 1923	7.9	30.8	230.8	152.8	1.51	4.21	.000139	62.4	.031	
27	Jan. 21, 1923	8.0	31.0	228.0	155.5	1.47	4.26	.000128	63.0	.031	

DITCH NO. 1 NEAR CHAFFEE, MO., AFTER GROWTH OF WILLOWS

28	Nov. 29, 1925	6.6	27.4	81.7	115.0	0.71	3.66	0.000186	27.2	0.069	Same channel as above with about 2 years' growth of willows. (Pl. 21, C.)
29	Nov. 28, 1925	7.4	29.7	99.6	136.5	.73	3.98	.000192	26.4	.073	
	----------	[1] 8.0	----------	----------	----------	----------	----------	----------	----------	----------	

SALS CREEK ROCK CHANNEL NEAR ANCELL, MO., ORIGINAL

30	May 22, 1922	5.6	10.1	160.0	46.2	3.46	2.56	0.00279	41.0	0.042	*Course*, straight; 161 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 18, E. *Side slopes*, quite irregular. *Bottom*, fairly even, some irregularities. *Soil*, limestone rock. *Condition*, ragged projecting rocks as excavated by explosives. *Constructed*, December, 1921. (Pl. 23, B and fig. 17, E.)
31	do	5.9	10.2	177.9	48.4	3.68	2.62	.00274	43.5	.039	
	----------	[1] 8.0	----------	----------	----------	----------	----------	----------	----------	----------	

SALS CREEK ROCK CHANNEL NEAR ANCELL., MO., ENLARGED

32	July 12, 1924	2.5	15.4	115.0	35.6	3.23	1.93	0.001898	53.4	0.030	*Course*, straight; 250 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 18, F. *Side slopes*, fairly regular. *Bottom*, quite even and regular. *Soil*, limestone rock. *Condition*, same channel as above, enlarged and smoothed by hand. *Constructed*, December, 1922. (Pl. 23, C and fig. 17, F.)
33	July 10, 1924	2.9	15.6	146.2	42.0	3.48	2.19	.001898	53.9	.031	
34	Jan. 30, 1923	3.1	15.8	156.9	45.0	3.49	2.30	.001750	55.0	.030	
35	Mar. 18, 1927	3.8	16.1	230.3	56.6	4.07	2.68	.002872	46.4	.037	
36	Feb. 1, 1923	4.3	16.3	265.2	63.3	4.19	2.88	.002690	47.6	.037	
37	Mar. 18, 1927	4.3	16.3	280.8	64.1	4.38	2.91	.002913	47.6	.037	
38	do	4.7	16.6	353.5	71.5	4.94	3.10	.003142	50.0	.036	
39	Mar. 31, 1927	7.2	17.7	810.6	112.8	7.19	4.01	.003721	58.8	.032	
40	June 13, 1927	7.4	17.8	884.5	116.4	7.60	4.08	.003529	63.3	.030	
41	Mar. 31, 1927	7.5	17.9	901.2	119.0	7.57	4.13	.004198	57.5	.033	
42	June 13, 1927	7.8	18.0	957.5	123.9	7.73	4.21	.004129	58.6	.033	
43	do	7.8	18.0	995.7	124.1	8.02	4.22	.004937	55.6	.034	
44	do	7.9	18.1	1,020.8	127.0	8.04	4.28	.005018	54.8	.035	
45	do	8.0	18.2	1,008.5	128.8	7.83	4.31	.004659	55.3	.035	
46	do	8.1	18.2	1,077.0	130.4	8.26	4.33	.004957	56.4	.034	

[1] Average maximum depth at bankful stage.

MAIN DIVERSION FLOOD WAY

Discharge and slope measurements were made on a cleared course and on an uncleared course in a straight stretch of the flood way near Nash, Mo. The length of each course was 3,000 feet. The flood way lies between levees that are about 1,100 feet apart. Along the flood-way side of the south levee is a large excavated channel. To eliminate the effect of the higher velocities in this channel, the values of *n* were computed for a width of about 825 feet, bounded by the north levee and a line approximately 30 feet outside the channel. A view of the cleared course of the flood way is shown in Plate 22, A. The clearing of this course was completed about one month before the measurements were made. Everything was cleared from the flood way except the stumps and, in places, a growth of dry slough grass which did not exceed 3 or 4 inches in height. The stumps ranged in height from 1¼ to 2 feet, the average being about 1.6 feet, and ranged in diameter from 6 inches to 4 feet. The average number of stumps

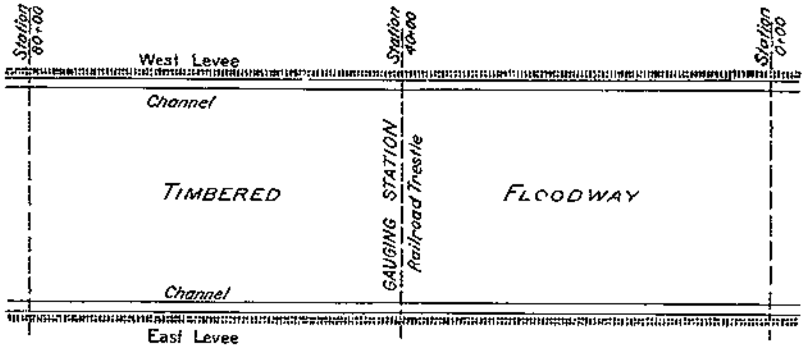
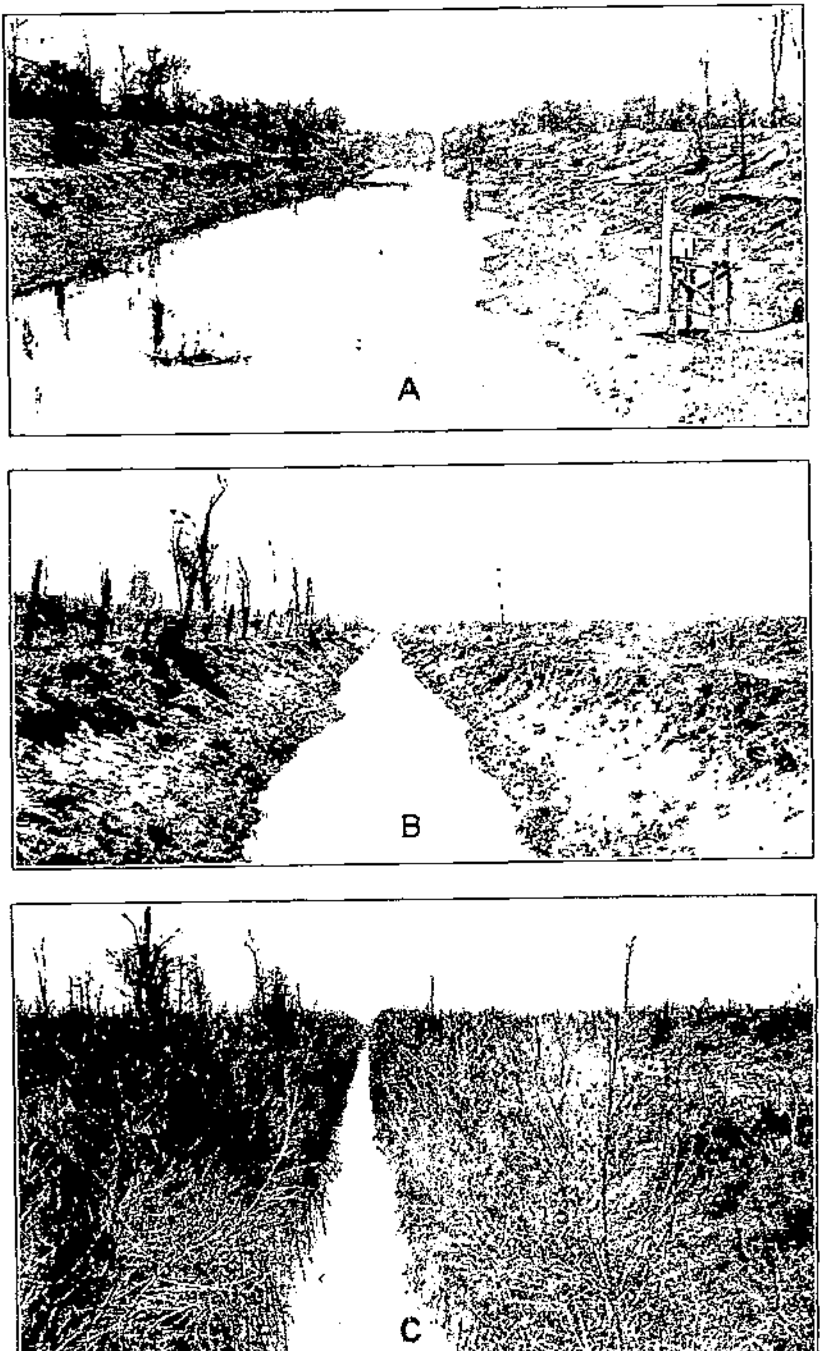


FIGURE 16.—Slope course St. Francis River flood way near Marked Tree, Ark.

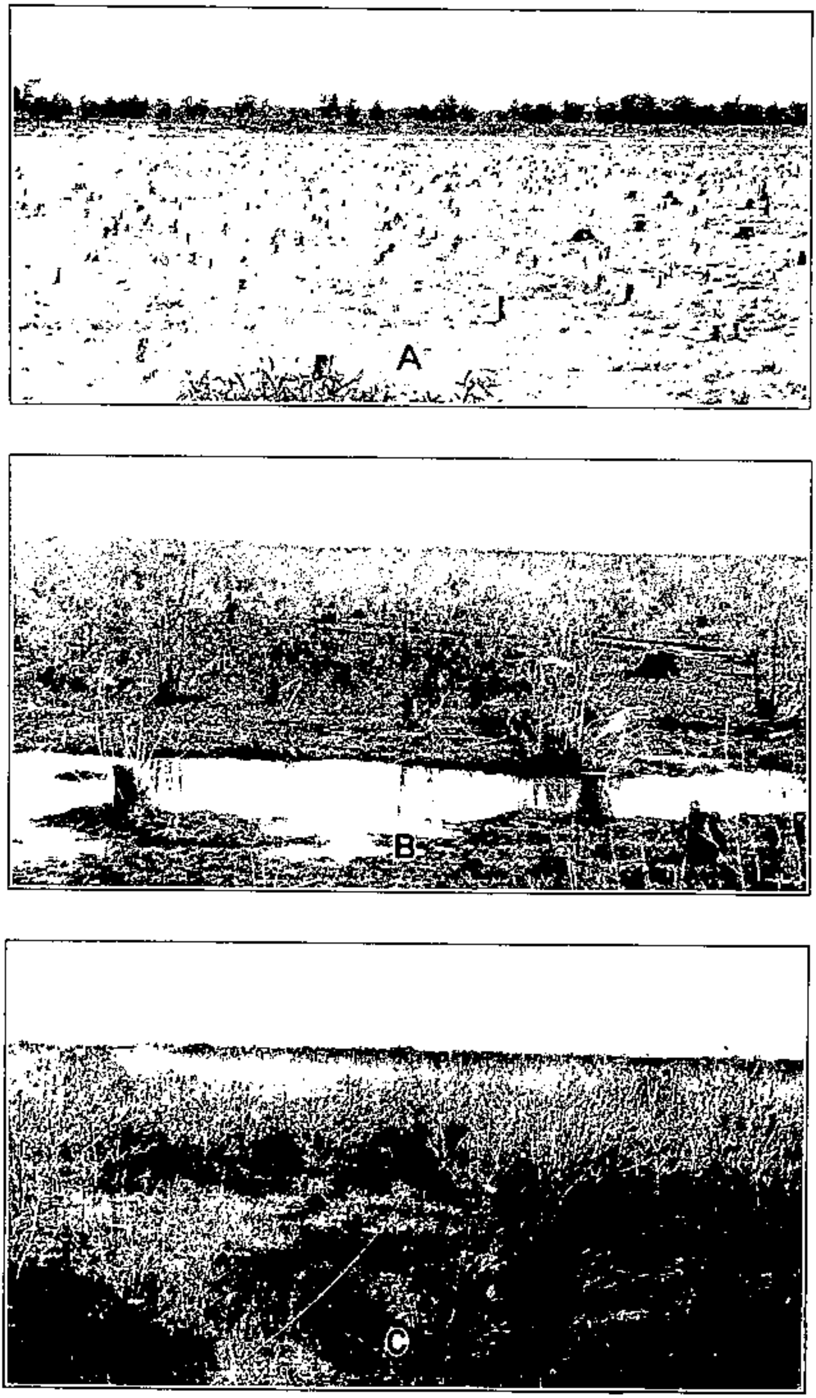
per acre was about 117, and the 6-inch to 18-inch stumps constituted about 88 per cent of the total number.

The condition of the uncleared course is shown by two views in Plate 22. This portion of the flood way had been cleared about three or four years before the views were taken, and the growth shown consisted principally of willows and sprouts from the stumps. There was very little undergrowth such as vines and weeds, and the condition as regards grass and stumps was similar to that of the cleared portion of the flood way. There were a few logs and some drift along the course. (See figs. 17, A; 17, B; 18, A; and 18, B, for average cross section and variation of cross sections along the slope courses.)

Current meter measurements were made at 40-foot intervals across the flood way. They were made from a boat attached to a cable wire stretched across the flood way midway the length of each slope course. As extreme care was exercised in making all the measurements for determining the values of *n*, it is believed that the results are quite accurate. Table 8 gives the results of the experiments. The average value of *n* was found to be 0.046 for the cleared course and 0.076 for the uncleared course, for depths of water ranging from 4.4 to 5.5 feet. The great difference in the values of *n* obtained for the cleared and the uncleared courses emphasizes the importance of systematic maintenance for flood ways to prevent marked reductions in their capacities.



A, Ditch No. 19 of Cypress Creek drainage district, near Dumas, Ark., looking up slope course, March, 1926 (see Table 7); B, Ditch No. 1 of Little River drainage district, near Chaffee, Mo., looking down slope course, April, 1923 (see Table 8); C, same view as B, above, in December, 1925. Ditch was cleared in late summer of 1923 (see Table 8)



Main diversion floodway of Little River drainage district near Nash, Mo. A, Looking across cleared slope course, March, 1922; B, looking across uncleared slope course, November, 1922; C, another view of the uncleared course, November, 1922. (See Table 8)

For a more detailed description of these experiments, the reader is referred to a report on The Flow of Water in the Main Diversion Flood way of the Little River Drainage District in Southeast Missouri.[4]

EXCAVATED CHANNEL IN MAIN DIVERSION FLOOD WAY

Gagings of this channel were made from a cable and car gaging station near Nash, Mo. This channel is located along the south side of the flood way. (Fig. 17, A.) The course used for slope measurements was straight and 3,000 feet long. The average maximum depth of the channel was 20.5 feet, and the top width about 145 feet. (Fig. 17, C.) For the measurements shown in Table 8, the depth of flow over the banks ranged from 2 to 5½ feet. The wetted perimeter for all of the measurements was taken the same as the wetted perimeter for the channel at bank-full stage. The left bank of the channel for the full length and the right bank along the upper half of the slope course were very irregular. The right bank was paved with rock along the lower half of the course. (Pl. 23, A.) There was practically no vegetation in the channel. Variations in the size of the cross section were small. (Fig. 18, C.)

The values of n obtained for this channel range from 0.033 to 0.037, which are rather high for a channel free from vegetation. It is believed that the great irregularities in the side slopes and bottom, due to erosion and caving banks, account for the high values obtained.

DITCH NO. 1

Gagings of this ditch were made from a single-span private wagon bridge about one-half mile northwest of Chaffee, Mo. The slope course was straight and 800 feet in length. Values of n were obtained for two different conditions of channel, views of which are shown in Plate 21. Values were obtained for stages ranging from low to bankful before the growth of willows in the channel, and for two high stages after the growth of willows was about 2 years old. (For average cross section and variation in size, see figs. 17, D and 18, D.)

It will be seen from Table 8 that the values of n for the cleared and the uncleared conditions of channel were about 0.030 and 0.070, respectively. The channel carried 75 per cent more water when cleared than when uncleared (at depths of 6.4 to 7.6 feet), although the surface slope was little more than half (55 per cent) as great. Computations based on the values of n show the capacity to have been 2.3 times as great when the channel was cleared as when obstructed with the willows.

It will also be seen from Table 8 that the values of n for the cleared channel increase with an increase in depth of flow, from low to nearly bankful stage. The higher part of the side slopes was quite irregular as compared with the lower part, which accounts for the higher values of n.

SALS CREEK ROCK CHANNEL

Discharge measurements on this channel were made from a log footbridge about 1 mile west of Ancell, Mo. This channel was originally excavated by blasting, but its capacity was found to be

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[4] RAMSER, C. E., and BARTZ, H. J. THE FLOW OF WATER IN THE MAIN DIVERSION FLOODWAY OF THE LITTLE RIVER DRAINAGE DISTRICT IN SOUTHEAST MISSOURI. 14 p., illus. [Washington, D.C.] 1924. (U.S. Dept. Agr., Bur. Pub. Roads.) [Mimeographed.]

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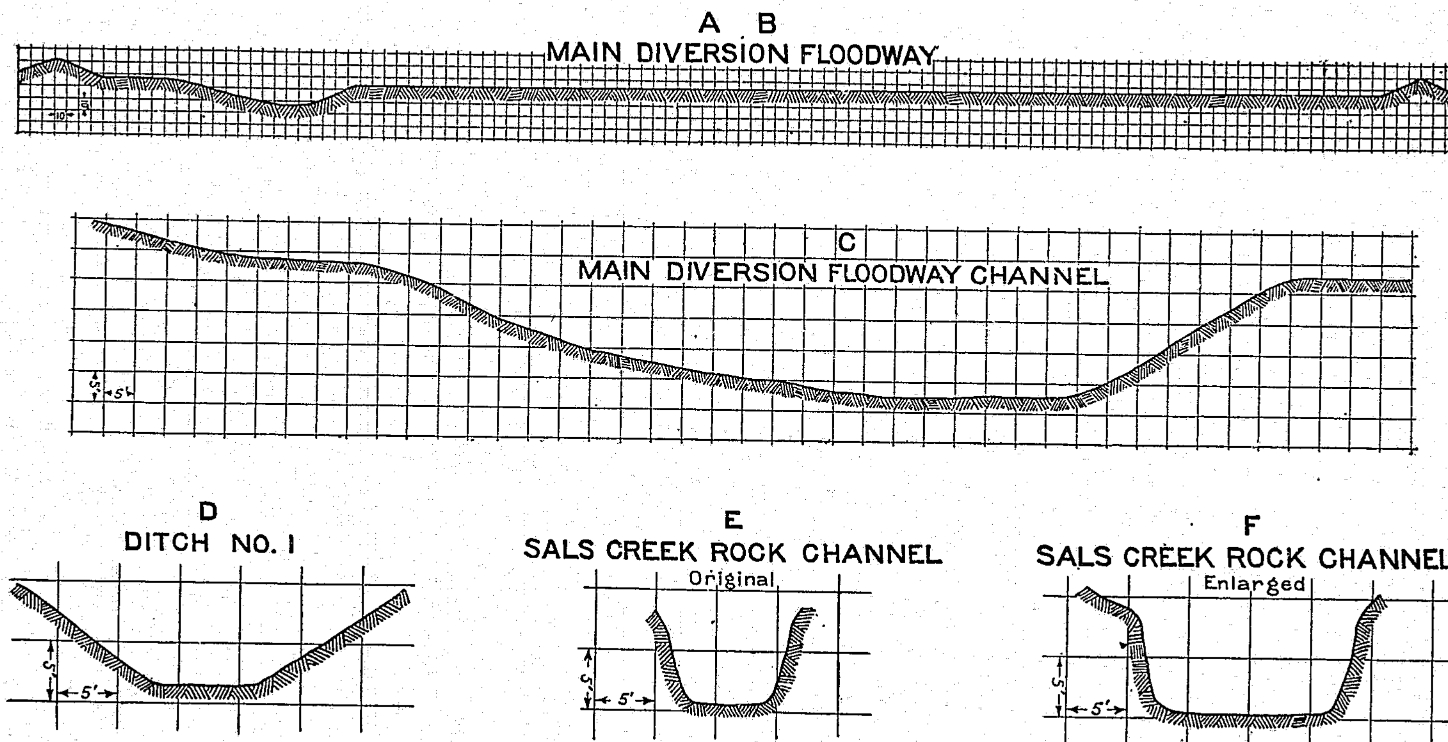


FIGURE 17.—Average cross sections of channels for experiments in southeastern Missouri

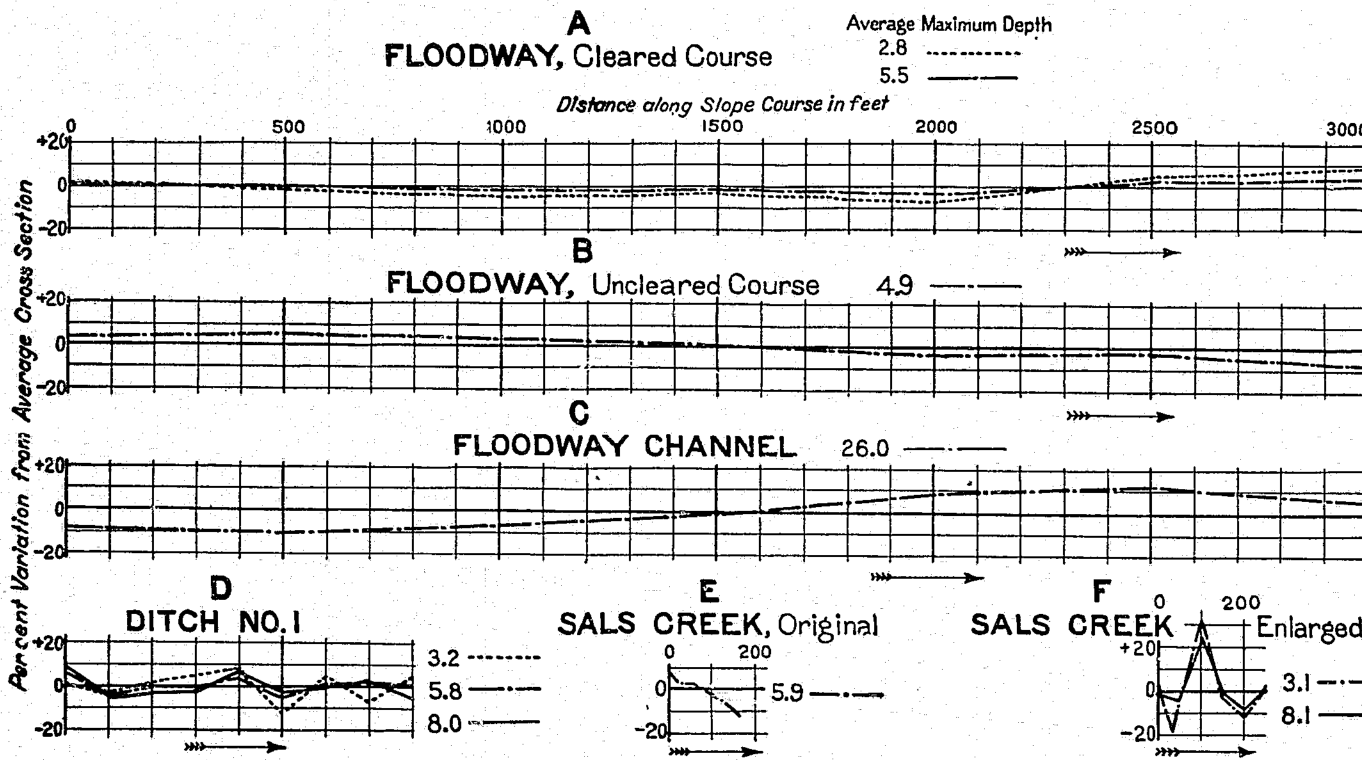


FIGURE 18.—Graphs for experiments in southeastern Missouri, showing per cent variation from average cross-sectional area for all cross sections along slope courses

inadequate, so it was later enlarged by hand labor. (Figs. 17 E and 18, F.) The slope was measured along a straight course, 161 feet in length before the channel was enlarged and 250 feet in length after the improvement was made. The sides of the original channel were very rough, consisting of the jagged ends of rocks shattered by the explosives. The sides of the enlarged channel were comparatively smooth. (Pl. 23.) The bottom of the channel was quite even and regular. The original channel increased in cross section rather gradually from the upper to the lower end of the slope course, while in the enlarged channel there were very abrupt variations. (Figs. 18, E and 18, F.) Some of the irregularities in the enlarged channel were due to caving in of the rather loose rock after being saturated by a high stage of water.

Table 8 shows somewhat larger values of n for the original than for the enlarged channel. It is believed that this difference would have been greater if the variations in cross-sectional area had not been larger and more abrupt in the enlarged channel than in the original. The lower values of n obtained for the three lowest stages were likely due to the comparatively smooth and even condition of the channel bottom.

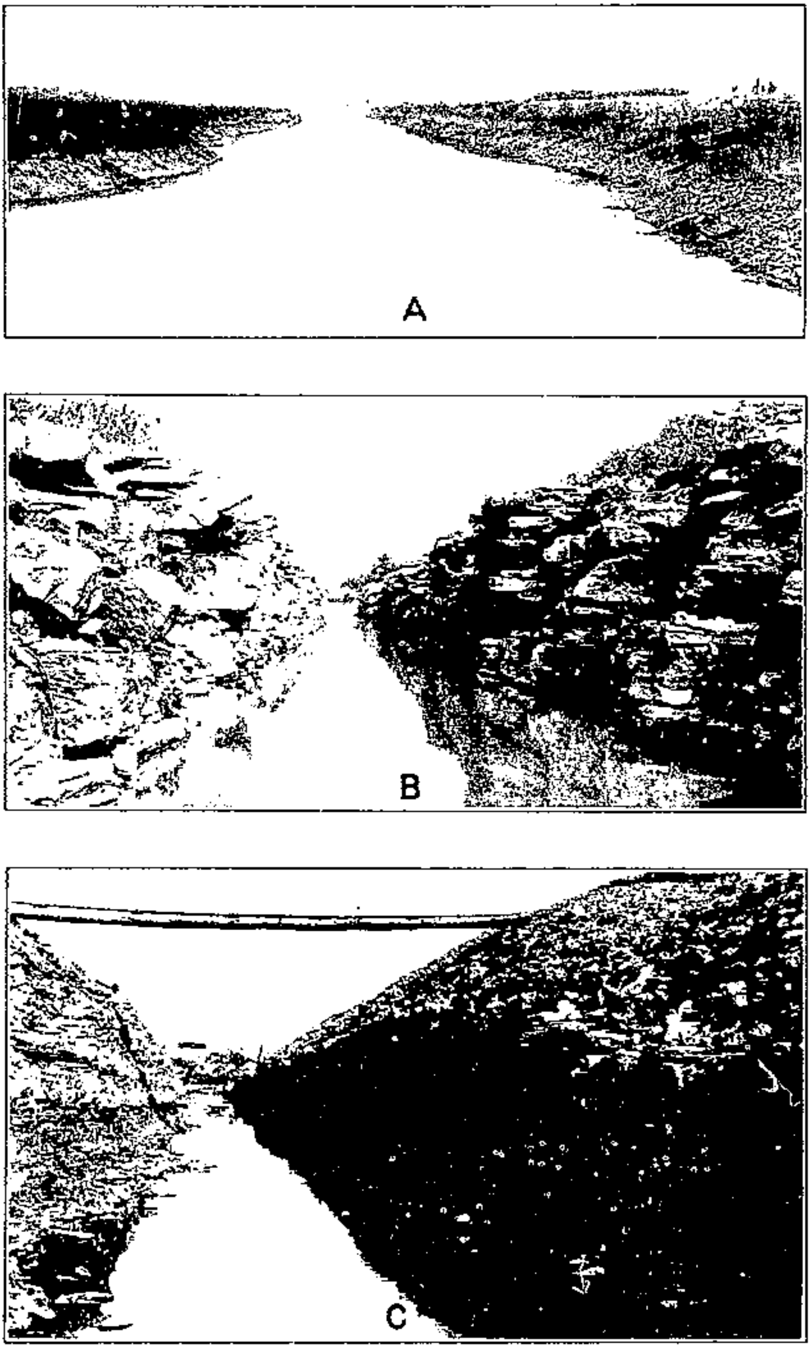
DISCUSSION OF MISSOURI EXPERIMENTS

The flood way experiments are the first, to the author's knowledge, that ever have been made on both cleared and uncleared sections of a large flood way so that a direct comparison could be made. The results should be of considerable value in the design of flood ways where conditions are expected to be similar, and, with the results of the later experiments on St. Francis River flood way (Table 7), as a general guide in the design of most flood ways. However, it is fully realized that further investigations are much needed to furnish engineers with more complete data relative to flow in such waterways and the effect of removing the trees and brush.

It is believed that the results obtained for ditch No. 1 are representative of small ditches in the flat lands of southeastern Missouri. The results show that where the growth of vegetation is rapid and the ditch is dry for long periods in the summer, annual clearing is necessary to keep the ditch in fairly good condition. Even where annual clearing is to be employed, it is not believed advisable to use a value of n less than 0.035 in design.

Although the large excavated channel in the flood way is self-maintaining to the extent of preventing growth of vegetation, its side slopes are extremely irregular due to rapid erosion and caving of banks. It is not believed that a value of n of less than 0.035 should be used in the design of a channel subject to such high velocities as are likely to cause great irregularities in the side slopes.

The results obtained for the two conditions of the Sals Creek rock channel are of value for use in the design of similar channels in any section of the country.



A, Excavated channel on main diversion floodway of Little River drainage district, near Nash, Mo., looking down slope course, November, 1922. B, Sals Creek rock channel of Little River drainage district, near Ancell, Mo., channel excavated by explosives, looking down slope course, July, 1922; C, same view as B, above, in March, 1924, channel had been enlarged and smoothed by hand labor, since the earlier view. (See Table 8)

TABLE 9.—*Results of experiments in central Illinois*

NATURAL CHANNEL OF EMBARRASS RIVER NEAR CHARLESTON, ILL.

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
		Feet	*Feet*	*Second-feet*	*Sq. ft.*	*Ft. per sec.*	*Feet*				
1	Apr. 13, 1926	8.7	139.3	1,974.9	945.3	2.09	6.52	0.000136	70.2	0.030	*Course*, straight; 1,000 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 20, A. *Side slopes*, somewhat irregular. *Bottom*, fairly even and regular. *Soil*, lower part, light gray silty clay; upper part, light tan silt loam. *Condition*, bottom comparatively clean and smooth, upper part of side slopes covered with large trees; natural channel. (Pl. 24, A and fig. 19, A.)
2	Feb. 27, 1926	9.9	146.4	2,500.7	1,119.2	2.23	7.32	.000128	72.9	.030	
3	Apr. 10, 1926	13.5	180.0	4,265.4	1,700.1	2.51	9.04	.000128	73.8	.031	
4	Sept. 14, 1926	13.7	182.1	4,318.9	1,740.7	2.48	9.15	.000128	72.5	.032	
5	Sept. 12, 1926	16.2	219.1	5,868.6	2,275.5	2.58	9.95	.000140	69.1	.034	
6	Sept. 9, 1926	17.6	237.4	6,237.4	2,605.8	2.39	10.45	.000087	79.3	.030	
7	Oct. 5, 1926	[1] 19.3	243.2	8,857.0	3,011.6	2.94	11.72	.000175	64.9	.038	

LAKE FORK SPECIAL DREDGED CHANNEL NEAR BEMENT, ILL., WINTER AND SPRING CONDITIONS (UNCLEARED)

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
8	Mar. 26, 1925	4.2	39.1	133.7	107.8	1.24	2.62	0.000273	46.4	0.037	*Course*, straight; 816 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 20, B. *Side slopes*, fairly regular. *Bottom*, uneven and irregular. *Soil*, lower part, light gray clay; upper part, yellowish gray clay. *Condition*, side slopes covered with dense growth of bushy willows, except near bottom: some small poplar saplings at intervals along course; one silt bar about middle of course, otherwise bottom in quite good condition. *Constructed*, 1885; redredged, 1909. (Pl. 25, A and fig. 19, B.)
9	Apr. 29, 1924	4.8	42.4	151.0	133.3	1.13	2.96	.000250	41.6	.042	
10	Apr. 28, 1924	5.6	45.2	200.4	166.4	1.20	3.45	.000241	41.8	.044	
11	do	5.7	45.6	198.9	172.4	1.15	3.55	.000240	39.5	.047	
12	June 9, 1924	6.6	48.4	242.8	214.1	1.13	4.11	.000260	34.7	.056	
13	June 7, 1924	7.4	50.7	303.8	251.4	1.21	4.56	.000248	35.9	.056	
14	Mar. 16, 1925	7.4	50.9	256.4	254.3	1.01	4.60	.000240	30.4	.066	
15	Dec. 22, 1924	7.5	51.1	276.5	259.5	1.07	4.67	.000224	33.0	.061	
16	June 6, 1924	7.9	52.2	320.6	279.2	1.15	4.91	.000281	30.9	.067	
17	Mar. 14, 1925	9.3	55.4	396.1	354.1	1.12	5.78	.000261	28.8	.076	
18	Mar. 19, 1925	10.1	57.2	455.6	400.5	1.14	6.26	.000266	27.9	.080	
19	Oct. 8, 1926	11.6	60.7	560.1	489.2	1.14	7.14	.000254	26.9	.088	
20	Oct. 3, 1926	13.3	64.9	734.3	595.2	1.23	8.03	.000255	27.3	.090	
		[1] 13.0									

[1] Average maximum depth at bankful stage.

TABLE 9.—*Results of experiments in central Illinois*—Continued

LAKE FORK SPECIAL DREDGED CHANNEL NEAR BEMENT, ILL., SUMMER AND FALL CONDITIONS (UNCLEARED)

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
		Feet	*Feet*	*Second-feet*	*Sq. ft.*	*Ft. per sec.*	*Feet*				
21	Sept. 17, 1926	6.8	48.8	185.1	221.4	0.84	4.20	0.000241	26.3	0.075	*Condition*, about the same as for above measurements, except that growth was covered with foliage. This channel was cleared during fall of 1925, but there appeared to be as much growth in channel by the fall of 1926 as previous to clearing. (Pl. 25, B.)
22	Sept. 7, 1926	7.4	50.8	192.2	253.7	.76	4.60	.000244	22.6	.090	
23	Aug. 25, 1924	8.0	52.3	259.7	282.3	.92	4.94	.000286	24.5	.085	
24	Sept. 6, 1926	8.5	53.6	244.4	309.6	.79	5.27	.000239	22.3	.096	
25	Sept. 5, 1926	9.2	55.2	282.5	347.7	.81	5.71	.000228	22.5	.098	
26	Sept. 13, 1926	9.6	56.1	319.7	372.2	.86	5.96	.000214	24.0	.093	
27	Sept. 10, 1926	12.0	61.6	495.2	511.0	.97	7.33	.000236	23.3	.104	

LAKE FORK SPECIAL DREDGED CHANNEL NEAR BEMENT, ILL., WINTER AND SPRING CONDITIONS (CLEARED)

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
28	Jan. 19, 1926	4.5	40.8	158.0	120.4	1.31	2.78	0.000186	57.7	0.030	*Condition*, practically no growth in channel; cleared during fall of 1925. (Pl. 25, C.)
29	Feb. 26, 1926	6.1	46.8	296.1	189.7	1.56	3.79	.000169	61.7	.030	
30	Apr. 9, 1926	6.8	48.8	332.0	220.7	1.50	4.19	.000146	60.8	.032	
31	Apr. 8, 1926	7.9	52.2	461.1	279.6	1.65	4.91	.000142	62.4	.032	
	----------	[1] 13.0	----------	----------	----------	----------	----------	----------	----------	----------	

WEST BRANCH OF SALT FORK DREDGED CHANNEL NEAR URBANA, ILL., CLEARED COURSE, WINTER AND SPRING CONDITIONS

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
32	May 1, 1924	2.7	29.2	148.4	57.5	2.58	1.84	0.000844	65.4	0.025	*Course*, straight; 480 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 20, C. *Side slopes*, fairly regular. *Bottom*, quite flat but somewhat irregular in places. *Soil*, bottom covered with stones and gravel; upper part, bowlder clay with oxidized iron. *Condition*, some small sprouts, bushes and dead grass on side slopes, without foliage; bottom covered with mossy stones at lower end of course, but mostly with gravel at upper end. *Constructed*, about 1908 (Pl. 24, B and fig. 19, C.)
33	Apr. 26, 1924	2.9	30.6	151.2	65.4	2.31	2.01	.000898	54.5	.030	
34	Mar. 20, 1925	3.9	35.5	286.1	91.5	3.13	2.42	.000933	65.8	.026	
35	Feb. 9, 1925	4.1	39.4	301.1	105.7	2.85	2.53	.001085	54.3	.031	
36	Mar. 19, 1925	4.9	45.5	481.5	141.4	3.41	2.93	.000806	70.0	.025	
37	Mar. 14, 1925	5.3	47.7	483.1	161.7	2.99	3.20	.000744	61.3	.029	
38	Apr. 8, 1926	5.8	49.8	666.7	185.3	3.60	3.52	.000958	62.0	.030	
39	Feb. 25, 1926	5.9	49.8	625.0	186.2	3.36	3.53	.000854	61.2	.030	
40	Dec. 19, 1924	6.1	51.0	699.7	201.3	3.48	3.72	.000704	67.9	.027	
41	do	6.8	53.4	806.4	237.1	3.40	4.14	.000704	63.0	.030	
42	Apr. 7, 1926	9.5	63.6	1,402.0	392.5	3.57	5.71	.000552	63.6	.032	

[1] Average maximum depth at bankful stage.

WEST BRANCH OF SALT FORK DREDGED CHANNEL NEAR URBANA, ILL., CLEARED COURSE, SUMMER AND FALL CONDITIONS

43	Sept. 14, 1925	3.2	32.0	153.1	72.7	2.11	2.11	0.001352	39.4	0.041	*Condition*, as above, but with heavy mat of short grass on side slopes and with foliage on the bushes.
44	Sept. 28, 1926	3.6	34.6	226.3	86.2	2.63	2.34	.001367	46.5	.036	
45	Aug. 20, 1924	4.1	38.5	307.3	102.5	3.00	2.51	.001067	57.9	.029	
46	Sept. 13, 1925	4.6	43.7	370.6	127.9	2.90	2.76	.001340	47.7	.036	
47	Oct. 1, 1926	5.2	46.9	468.3	154.4	3.03	3.11	.001135	51.1	.035	
48	Sept. 4, 1926	6.4	52.2	696.1	216.7	3.21	3.92	.001077	49.5	.038	
49	Oct. 2, 1926	7.6	55.8	993.0	278.1	3.57	4.64	.000935	54.2	.036	
	----------	[1] 10.0	----------	----------	----------	----------	----------	----------	----------	----------	

WEST BRANCH OF SALT FORK DREDGED CHANNEL NEAR URBANA, ILL., UNCLEARED COURSE

50	May 1, 1924	3.4	29.4	148.4	80.4	1.85	2.50	0.001118	34.9	0.048	*Course*, straight; 550 feet long. *Cross section*, some variation in shape; for variation in size, see fig. 20, D. *Side slopes*, irregular. *Bottom*, rather irregular. *Soil*, lower part, probably clay originally but now mixed with a large percentage of sand; upper part, bowlder clay, quite stony. *Condition*, side slopes covered with rather thick growth of small trees and sprouts of maple, elm, poplar, box elder, and some willow, from ½ inch to 8 inches in diameter; no grass; stones on bottom up to 1 foot in diameter; no appreciable silting. *Constructed*, about 1908. (Pl. 24, C and fig. 19, D.)
51	Apr. 26, 1924	3.6	31.0	151.2	89.6	1.69	2.65	.001216	29.7	.057	
52	Sept. 14, 1925	3.9	32.3	153.1	97.9	1.56	2.77	.000838	32.5	.053	
53	Sept. 28, 1926	4.2	34.4	226.3	109.1	2.07	2.92	.000924	39.9	.044	
54	Jan. 18, 1926	4.4	35.6	202.8	114.5	1.77	2.95	.001087	31.3	.056	
55	Mar. 20, 1925	4.5	36.7	286.1	119.3	2.40	3.01	.001111	41.5	.043	
56	Feb. 9, 1925	4.8	38.6	301.1	129.4	2.33	3.09	.001240	37.6	.047	
57	Mar. 29, 1924	5.1	41.1	392.6	142.5	2.76	3.20	.001587	38.6	.047	
58	Sept. 13, 1925	5.3	42.4	370.6	149.8	2.47	3.25	.001220	39.3	.046	
59	Mar. 19, 1925	5.7	44.5	481.5	165.9	2.90	3.43	.001427	41.5	.044	
60	Oct. 1, 1926	5.9	45.7	462.3	176.1	2.66	3.56	.001284	39.3	.047	
61	Mar. 14, 1925	6.1	46.4	483.1	185.8	2.60	3.69	.001435	35.7	.052	
62	Feb. 25, 1926	6.5	48.1	625.0	208.0	3.00	3.91	.001825	35.6	.053	
63	Apr. 8, 1926	6.6	48.2	666.7	208.5	3.20	3.92	.001531	41.3	.046	
64	Dec. 19, 1924	6.9	49.8	699.7	225.7	3.10	4.10	.001733	36.8	.052	
65	Sept. 4, 1926	7.0	50.0	696.1	227.8	3.06	4.12	.001282	42.1	.046	
66	Oct. 2, 1926	8.3	54.5	993.0	297.5	3.34	4.91	.001385	40.5	.050	
67	Apr. 7, 1926	10.2	60.5	1,402.0	405.2	3.46	5.99	.001885	32.6	.066	
	----------	[1] 10.0	----------	----------	----------	----------	----------	----------	----------	----------	

EAST LAKE FORK DREDGED CHANNEL NEAR IVESDALE, ILL., WINTER CONDITIONS, CLEARED

68	Mar. 13, 1925	3.1	22.0	53.9	48.3	1.12	2.06	0.000295	45.3	0.035	*Course*, straight; 800 feet long. *Cross section*, very little variation in shape; for variation in size, see Figure 20, E. *Side slopes*, rather irregular. *Bottom*, uneven and rather irregular. *Soil*, lower part, yellowish gray clay; upper part dark-gray silt loam. *Condition*, dead weeds and stubble on side slopes; channel had been cleared shortly before March, 1925. *Constructed*, 1885; redredged about 1904. (Pl. 26, A and fig. 19, E.)
69	Mar. 16, 1925	4.1	25.4	117.2	72.5	1.62	2.63	.000306	57.0	.030	
70	Mar. 14, 1925	5.2	28.4	152.0	101.7	1.49	3.24	.000246	52.9	.034	
71	Mar. 19, 1925	5.8	29.2	179.6	117.7	1.53	3.53	.000250	51.3	.036	

[1] Average maximum depth at bankful stage.

TABLE 9.—*Results of experiments in central Illinois*—Continued

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
		Feet	*Feet*	*Second-feet*	*Sq. ft.*	*Ft. per sec.*	*Feet*				
	EAST LAKE FORK DREDGED CHANNEL NEAR IVESDALE, ILL., WINTER CONDITIONS, UNCLEARED										
72	Nov. 9, 1925	3.1	22.0	35.4	48.8	0.73	2.08	0.000295	29.3	0.054	*Condition*, dense new growth of willows on right slope in channel, willows and box elders on left slope; no foliage at this season.
73	Mar. 20, 1926	3.5	23.2	47.3	57.6	.82	2.28	.000379	28.0	.058	
74	Feb. 26, 1926	5.3	28.7	119.1	104.1	1.14	3.28	.000340	34.2	.053	
	EAST LAKE FORK DREDGED CHANNEL NEAR IVESDALE, ILL., FALL CONDITIONS, UNCLEARED										
75	Sept. 7, 1926	5.2	28.4	64.0	101.6	0.63	3.24	0.000326	19.4	0.093	*Condition*, left side rather steep, showing some tendency to cave; brush larger on side slopes; foliage on all vegetation. (Pl. 26, B.)
76	Sept. 5, 1926	6.1	30.5	77.2	126.8	.61	3.70	.000272	19.0	.100	
77	Sept. 13, 1926	7.2	33.5	124.6	162.1	.77	4.25	.000330	20.5	.097	
78	Sept. 11, 1926	8.8	41.3	170.8	222.2	.77	4.75	.000308	20.1	.103	
	----------	[1] 9.5	----------	----------	----------	----------	----------	----------	----------	----------	
	KASKASKIA MUTUAL DREDGED CHANNEL NEAR BONDVILLE, ILL., LOWER COURSE, WINTER AND SPRING CONDITIONS										
79	Feb. 7, 1925	2.4	18.1	21.9	29.8	0.73	1.50	0.000527	26.2	0.054	*Course*, nearly straight; 330 feet long. *Cross section*, some variation in shape; for variation in size, see Figure 20, F.
80	Mar. 16, 1925	3.3	19.8	45.5	46.1	.99	2.09	.000503	30.5	.052	*Side slopes*, irregular. *Bottom*, irregular. *Soil*, lower part, black clay; upper part, dark-gray silty clay loam. *Condition*, badly obstructed by trees 2 to 12 inches in diameter covering side slopes, except intervals aggregating half length of right bank occupied by large weeds and bushy willows; no foliage. *Constructed*, 1902; cleared, about 1910. (Pl. 27, A and fig. 19, F.)
81	Feb. 25, 1926	6.1	29.3	100.7	114.5	.88	3.44	.000397	23.8	.077	
	KASKASKIA MUTUAL DREDGED CHANNEL NEAR BONDVILLE, ILL., LOWER COURSE, SUMMER CONDITIONS, 1924										
82	Aug. 8, 1924	4.4	24.0	67.1	71.0	0.95	2.60	0.000591	24.1	0.070	*Condition*, as described above, but with summer foliage, and three-fourths of length of bottom covered with short weeds.
83	June 6, 1924	4.8	25.1	72.2	79.9	.90	2.82	.000500	24.1	.072	
84	----do----	5.4	26.9	85.6	96.5	.89	3.15	.000424	24.3	.074	
85	Aug. 21, 1924	6.4	30.5	120.4	124.8	.96	3.60	.000473	23.4	.080	
86	Aug. 20, 1924	8.8	40.8	206.1	207.4	.99	4.49	.000503	20.9	.097	

KASKASKIA MUTUAL DREDGED CHANNEL NEAR BONDVILLE, ILL., LOWER COURSE, FALL CONDITIONS, 1926

87	Sept. 28, 1926	4.3	23.8	48.0	68.8	0.70	2.58	0.000645	17.1	0.097	*Condition*, as in summer of 1924, but worse. (Pl. 27, B.)
88	Sept. 9, 1926	7.5	34.3	111.5	157.8	.71	4.05	.000388	17.8	.110	
89	Oct. 2, 1926	8.0	36.6	132.3	176.4	.75	4.24	.000409	18.0	.111	
90	do	8.6	40.0	160.6	200.9	.80	4.43	.000421	18.5	.109	
		[1] 9.0									

KASKASKIA MUTUAL DREDGED CHANNEL NEAR BONDVILLE, ILL., UPPER COURSE, WINTER AND SPRING CONDITIONS

91	Feb. 7, 1925	2.1	16.5	21.9	24.6	0.89	1.36	0.000473	35.1	0.040	*Course*, straight; 330 feet long. *Cross section*, some variation in shape; for variation in size, see Figure 20, G. *Side slopes*, rather irregular. *Bottom*, rather irregular. *Soil*, lower part, black clay; upper part, dark-gray silty clay loam. *Condition*, badly obstructed by trees 1 to 6 inches in diameter on side slopes and edges of bottom; some weeds but practically no grass; no foliage. *Constructed*, 1902; cleared, about 1910. (Pl. 27, C and fig. 19, G.)
92	Mar. 16, 1925	3.0	18.9	45.5	39.6	1.15	1.89	.000424	40.5	.039	
93	Mar. 29, 1924	5.3	27.6	106.7	92.8	1.15	3.00	.000367	34.6	.051	
94	Feb. 25, 1926	5.7	29.6	100.7	105.7	.95	3.19	.000394	26.9	.067	

KASKASKIA MUTUAL DREDGED CHANNEL NEAR BONDVILLE, ILL., UPPER COURSE, SUMMER CONDITIONS, 1924

95	Aug. 24, 1924	4.1	23.0	67.1	64.0	1.05	2.50	0.000494	29.8	0.056	*Condition*, as described above, but with summer foliage, and water weed on bottom along one-tenth of course.
96	June 6, 1924	4.4	24.1	72.2	71.9	1.00	2.66	.000409	30.4	.056	
97	do	5.0	26.8	85.6	88.1	.97	2.95	.000373	29.3	.060	
98	Aug. 21, 1924	6.1	30.9	120.4	116.6	1.03	3.36	.000427	27.3	.067	
99	Aug. 20, 1924	8.4	41.0	206.1	200.3	1.03	4.35	.000536	21.3	.094	

[1] Average maximum depth at bankful stage.

TABLE 9.—*Results of experiments in central Illinois*—Continued

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ *C*	Coefficient of roughness *n*	Description of channel
		Feet	*Feet*	*Second-feet*	*Sq. ft.*	*Ft. per sec.*	*Feet*				
	KASKASKIA MUTUAL DREDGED CHANNEL NEAR BONDVILLE, ILL., UPPER COURSE, FALL CONDITIONS, 1926										
100	Sept. 28, 1926	4.0	22.8	48.0	62.0	0.77	2.44	0.000491	22.4	0.073	*Condition*, as in summer of 1924, with more vegetation.
101	Sept. 9, 1926	7.1	34.2	111.5	149.0	.75	3.86	.000403	19.0	.101	
102	Oct. 2, 1926	7.6	36.0	132.3	168.1	.79	4.12	.000500	17.3	.114	
103	do	8.2	39.3	160.6	192.4	.83	4.35	.000497	17.9	.112	
		[1] 9.0									
	KASKASKIA RIVER DREDGED CHANNEL NEAR SADORUS, ILL., WINTER AND SPRING CONDITIONS, 1926										
104	Jan. 18, 1926	5.2	37.6	249.1	130.6	1.91	3.15	0.000383	54.9	0.033	*Course*, crooked; 600 feet long. *Cross section*, considerable variation in shape; for variation in size, see fig. 20, H. *Side slopes*, very irregular and uneven. *Bottom*, fairly even and regular. *Soil*, lower part, light bluish gray clay, which is hard, waxy, and slippery at the bottom; upper part, gray silt loam. *Condition*, very young growth and stubble on upper part of slopes, none on lower part; channel cleared in September, 1925. *Constructed*, 1907; vegetation cut about every 2 years. (Pl. 26, C and fig 19, H.)
105	Feb. 26, 1926	6.2	43.0	321.0	169.5	1.89	3.58	.000485	45.4	.041	
106	Feb. 25, 1926	7.1	47.1	415.6	210.0	1.98	4.04	.000515	43.4	.044	
107	Apr. 7, 1926	7.6	49.2	454.4	236.8	1.92	4.35	.000463	42.7	.046	
	KASKASKIA RIVER DREDGED CHANNEL NEAR SADORUS, ILL., SUMMER AND FALL CONDITIONS, 1925										
108	Sept. 14, 1925	2.1	22.9	47.4	39.9	1.19	1.62	0.000202	65.6	0.023	*Condition*, channel cleared just before these measurements.
109	Sept. 13, 1925	3.8	29.1	125.4	84.0	1.49	2.63	.000267	56.3	.030	
110	do	4.1	31.5	146.9	93.3	1.57	2.70	.000253	60.3	.029	
	KASKASKIA RIVER DREDGED CHANNEL NEAR SADORUS, ILL., SUMMER AND FALL CONDITIONS, 1926										
111	June 12, 1926	2.8	25.6	70.7	56.2	1.26	2.02	0.000273	53.6	0.030	*Condition*, left slope covered with weeds, right slope with willows, except near bottom.
112	Sept. 17, 1926	3.2	26.8	69.8	66.8	1.04	2.28	.000243	44.4	.037	
113	Sept. 7, 1926	4.2	31.5	99.3	95.1	1.04	2.74	.000265	38.7	.044	
114	Sept. 13, 1926	4.9	36.2	138.4	120.5	1.15	3.04	.000285	39.1	.045	
115	Sept. 6, 1926	6.4	43.8	197.1	177.5	1.11	3.68	.000270	35.2	.053	
116	Sept. 5, 1926	7.4	48.3	260.2	225.4	1.15	4.22	.000377	28.9	.068	
117	Sept. 11, 1926	8.4	51.6	320.8	273.2	1.17	4.76	.000362	28.3	.072	
		[1] 9.0									

TWO MILE SLOUGH DREDGED CHANNEL NEAR SADORUS, ILL., WINTER AND SPRING CONDITIONS

118	Mar. 13, 1925	2.7	18.3	25.6	32.6	0.79	1.64	0.000558	26.0	0.056	*Course*, straight; 360 feet long. *Cross section*, considerable variation in shape; for variation in size, see fig. 20, I. *Side slopes*, irregular. *Bottom*, very irregular. *Soil*, lower part, black slippery clay; upper part, gray silty clay loam. *Condition*, about 100 feet of course covered with dense growth of bushy willows, some in bottom; remainder of both slopes covered with weeds and a scattering growth of willows and poplars 1 to 6 inches in diameter; no foliage; some silting in bottom. *Constructed*, redredged 1905; cleared, 1921. (Pl. 28, A and fig. 19, I.)
119	Jan. 19, 1926	4.0	22.3	44.2	59.7	.74	2.43	.000550	20.3	.081	
120	Mar. 14, 1925	5.6	27.2	86.4	99.2	.87	3.25	.000464	22.4	.081	
121	Feb. 25, 1926	5.8	27.9	101.4	107.0	.95	3.41	.000447	24.3	.076	
122	Mar. 19, 1925	5.8	28.1	105.1	106.6	.99	3.38	.000422	26.1	.070	
123	Jan. 18, 1926	6.0	28.4	92.7	111.4	.83	3.49	.000531	19.3	.096	
124	Apr. 7, 1926	7.5	32.7	159.5	158.7	1.01	4.24	.000500	21.8	.091	

TWO MILE SLOUGH DREDGED CHANNEL NEAR SADORUS, ILL., SUMMER AND FALL CONDITIONS

125	Nov. 12, 1925	2.7	18.5	19.4	34.9	0.56	1.74	0.000525	18.4	0.079	*Condition*, as described above, but with much foliage, and covered for about 40 feet with growth resembling smart weed. (Pl. 27, B.)
126	June 12, 1926	3.7	21.5	37.0	54.1	.68	2.28	.000461	21.1	.076	
127	Sept. 13, 1926	5.4	26.6	50.4	94.1	.54	3.15	.000267	18.5	.096	
128	Sept. 29, 1926	5.9	28.1	67.2	108.3	.62	3.43	.000422	16.3	.113	
129	Sept. 25, 1926	6.5	29.8	69.3	126.6	.55	3.75	.000347	15.2	.126	
130	Sept. 11, 1926	7.9	33.8	99.7	171.6	.58	4.42	.000400	13.8	.147	
131	Oct. 6, 1926	8.7	36.3	147.5	197.3	.75	4.72	.000492	15.5	.134	
		[1] 9.5									

CAMP CREEK DREDGED CHANNEL NEAR SEYMOUR, ILL., WINTER CONDITIONS

132	Mar. 20, 1926	2.3	21.1	22.0	31.9	0.69	1.44	0.000519	25.2	0.055	*Course*, straight; 661 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 20, J. *Side slopes*, fairly regular. *Bottom*, uneven and irregular. *Soil*, lower part, yellowish gray clay; upper part, light gray silty clay loam. *Condition*, in 1924, newly cleaned leaving weeds and stubble on side slopes; in 1926, sides covered with trees and vines without foliage. *Constructed*, 1906; cleaned, winter of 1923-24. (Pl. 29, A and fig. 19, J.)
133	Apr. 29, 1924	3.0	23.4	39.3	46.4	.85	1.89	.000474	28.3	.054	
134	Apr. 26, 1924	3.1	23.8	42.3	49.5	.85	1.96	.000481	27.8	.055	
135	May 1, 1924	3.3	24.6	50.3	53.8	.93	2.07	.000470	30.0	.053	

CAMP CREEK DREDGED CHANNEL NEAR SEYMOUR, ILL., SUMMER CONDITIONS, 1924

136	June 10, 1924	3.9	26.4	46.3	68.4	0.68	2.42	0.000455	20.4	0.080	*Condition*, side slopes covered with weeds and a few young bushes in full leaf; short water growth resembling smart weed on bottom; channel cleaned in preceding winter. (Pl. 29, B.)
137	June 7, 1924	4.4	28.0	63.9	81.0	.79	2.69	.000466	22.3	.076	
138	June 6, 1924	5.2	30.2	97.0	105.2	.92	3.19	.000523	22.6	.079	

[1] Average maximum depth at bankful stage

TABLE 9.—*Results of experiments in central Illinois*—Continued

CAMP CREEK DREDGED CHANNEL NEAR SEYMOUR, ILL., SUMMER CONDITIONS, 1926

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient in formula $V=C\sqrt{RS}$ C	Coefficient of roughness n	Description of channel
		Feet	*Feet*	*Second-feet*	*Sq. ft.*	*Ft. per sec.*	*Feet*				
139	Sept. 10, 1926	4.6	28.6	60.9	87.9	0.69	2.84	0.000516	18.1	0.095	*Condition*, side slopes covered with heavy growth of poplar trees 2 to 3 inches in diameter, large willows, and climbing vines; thick growth of water weed on bottom. (Pl. 29, C.)
140	Oct. 2, 1926	7.3	36.0	164.9	175.7	.94	4.37	.000546	19.2	.104	
	------------	[1]8.5	------	------	------	------	------	------	------	------	

LATERAL DITCH NO. 15 NEAR BEMENT, ILL., SPRING CONDITIONS, 1925

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient C	Coefficient n	Description of channel
141	Mar. 26, 1925	1.8	15.0	17.8	18.0	0.99	1.16	0.000512	40.6	0.034	*Course*, straight; 1,000 feet long. *Cross section*, practically no variation in shape; for variation in size, see fig. 20, K. *Side slopes*, quite regular. *Bottom*, somewhat irregular. *Soil*, lower part, slippery gray clay; upper part, grayish tan silty clay loam. *Condition*, good; dead weeds practically flat on side slopes. *Constructed*, 1886; redredged, 1922. (Pl. 30, A and fig. 19, K.)
142	Mar. 16, 1925	2.6	17.3	28.7	30.5	.94	1.65	.000384	37.4	.040	
143	Mar. 14, 1925	3.8	20.0	77.7	53.4	1.46	2.39	.000237	61.1	.028	
144	Mar. 19, 1925	4.4	21.3	82.0	67.0	1.22	2.78	.000175	55.5	.031	

LATERAL DITCH NO. 15 NEAR BEMENT, ILL., SPRING CONDITION, 1926

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient C	Coefficient n	Description of channel
145	Apr. 9, 1926	3.9	20.4	58.7	56.9	1.03	2.50	0.000476	29.9	0.056	*Condition*, bushy willows and dry weeds on side slopes; no foliage.
146	Apr. 8, 1926	4.7	21.8	76.6	72.7	1.05	2.92	.000359	32.5	.054	

LATERAL DITCH NO. 15 NEAR BEMENT, ILL., SUMMER AND FALL CONDITIONS (BEFORE CAT-TAILS WERE WASHED OUT)

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coefficient C	Coefficient n	Description of channel
147	June 19, 1926	2.4	16.9	7.9	28.2	0.28	1.57	0.000572	9.4	0.143	*Condition*, weeds and willows in full leaf on side slopes; thick growth of cat-tails on bottom, which died and were washed out of channel about Nov. 15, 1925, and about Sept. 15, 1926. (Pl. 30, A and B.)
148	Nov. 10, 1925	2.9	18.0	14.7	35.8	.41	1.85	.000756	11.0	.131	
149	Sept. 7, 1926	5.0	22.4	45.1	78.5	.57	3.05	.000423	16.0	.110	
150	Sept. 6, 1926	6.0	24.4	62.8	103.7	.61	3.63	.000381	16.3	.115	
151	Sept. 5, 1926	7.2	26.4	84.6	132.1	.64	4.18	.000340	17.0	.117	
152	Sept. 10, 1926	8.2	28.3	110.9	161.2	.69	4.66	.000234	20.8	.099	

LATERAL DITCH NO. 15 NEAR BEMENT, ILL., FALL CONDITIONS (AFTER CAT-TAILS WERE WASHED OUT)

153	Sept. 17, 1926	3.7	19.8	30.8	51.1	0.60	2.33	0.000412	19.4	0.083	*Condition*, weeds and bushy willows in full leaf on side slopes; cat-tails had died and been washed from channel.
154	Oct. 6, 1926	7.4	26.8	89.2	138.5	.64	4.27	.000132	27.1	.073	
155	Oct. 2, 1926	[1] 10.6	33.2	398.5	233.5	1.71	5.61	.000413	35.4	.060	

FOUNTAIN HEAD DREDGED CHANNEL NEAR CHAMPAIGN, ILL., WINTER AND SPRING CONDITIONS

156	Mar. 13, 1925	2.3	16.0	43.4	22.8	1.90	1.32	0.000625	66.3	0.023	*Course*, straight; 800 feet long. *Cross section*, very little variation in shape; for variation in size, see fig. 20, L. *Side slopes*, irregular. *Bottom*, slightly irregular. *Soil*, upper part, black silty clay loam; lower part, waxy yellow to gray clay. *Condition*, dry weeds in channel; no willows or other trees. *Constructed*. 1908. (Pl. 31, A and fig. 19, L.)
157	Feb. 25, 1925	3.1	19.0	75.0	35.8	2.09	1.73	.000921	52.5	.030	
158	Oct. 2, 1926	3.7	21.0	126.4	48.8	2.59	2.12	.001308	49.1	.033	

FOUNTAIN HEAD DREDGED CHANNEL NEAR CHAMPAIGN, ILL., SUMMER AND FALL CONDITIONS

159	Sept. 9, 1926	3.4	20.1	94.5	42.0	2.25	1.93	0.001200	46.8	0.034	*Condition*, weeds and grass in channel; no trees or large brush. (Pl. 31, B.)
160	Sept. 4, 1926	3.9	21.5	122.6	53.3	2.30	2.26	.001339	41.8	.039	
161	Aug. 20, 1924	4.2	22.1	149.8	59.3	2.53	2.42	.001385	43.6	.038	
----	--------------	[1] 7.5	--------	--------	--------	--------	--------	--------	--------	--------	

STEWART BRANCH DREDGED CHANNEL NEAR CHAMPAIGN, ILL.

162	Sept. 30, 1926	2.3	17.0	12.4	19.2	0.65	1.06	0.003169	11.1	0.106	*Course*, crooked; 360 feet long. *Cross section*, considerable variation in shape; for variation in size, see fig. 20, M. *Side slopes*, irregular. *Bottom*, very irregular. *Soil*, lower part, dark gray clay with some sand and pebbles; upper part, dark gray silty clay loam. *Condition*, slopes covered with dense growth of tall weeds, bushes, and wiry grass; occasional bushy willows, and trees 6 to 9 inches in diameter; bottom very grassy, except narrow winding strip. *Constructed*, about 1890. (Pl. 28, C and fig. 19, M.)
163	Oct. 3, 1925	2.5	17.8	16.7	23.6	.71	1.23	.003406	10.9	.114	
164	Sept. 13, 1925	2.8	18.6	21.1	28.4	.74	1.41	.003422	10.7	.122	
165	Sept. 4, 1926	3.6	20.5	34.4	44.2	.78	1.96	.003131	9.9	.149	
166	Sept. 9, 1926	3.7	20.8	43.2	46.5	.93	2.02	.002956	12.0	.125	
	--------------	[1] 7.5	--------	--------	--------	--------	--------	--------	--------	--------	

ST. JOSEPH TOWNSHIP DITCH NO. 4 NEAR MAYVIEW, ILL.

167	Sept. 3, 1926	3.5	17.0	21.7	29.6	0.73	1.60	0.001145	17.1	0.082	*Course*, straight; 400 feet long. *Cross section*, very little variation in shape for variation in size, see fig. 20, N. *Side slopes*, fairly even and regular. *Bottom*, rather irregular. *Soil*, lower part, gray clay; upper part, crumbly dark gray silty clay loam. *Condition*, both side slopes covered with grass and dense growth of bushy willows; practically no vegetation in bottom. (Pl. 31, C and fig. 19, N.)
168	Sept. 4, 1926	4.4	19.2	48.0	53.4	.90	2.51	.001258	16.0	.103	
	--------------	[1] 7.3	--------	--------	--------	--------	--------	--------	--------	--------	

[1] Average maximum depth at bankful stage.

EXPERIMENTS IN CENTRAL ILLINOIS

The experiments in central Illinois were made on the following streams: Embarrass River, Lake Fork special ditch, West Branch of Salt Fork, East Lake Fork, Kaskaskia mutual ditch, Kaskaskia River, Two Mile Slough, Camp Creek, lateral ditch No. 15, Fountain Head, Stewart Branch, and St. Joseph Township ditch No. 4. The topography of the watersheds of these ditches is generally rather flat, but somewhat rolling in places.

EMBARRASS RIVER

Discharge measurements were made from a gaging station established on the North Ashmore steel highway bridge about 4½ miles northeast of Charleston, Ill. This bridge has a clear central span of 180 feet, which allows most of the water to flow between the round steel piers at either end of the span. The accuracy of the measurements is affected somewhat by the nearly stationary water at high stages between the piers and the banks of the stream. The slope was measured on a straight course 1,000 feet long below the bridge.

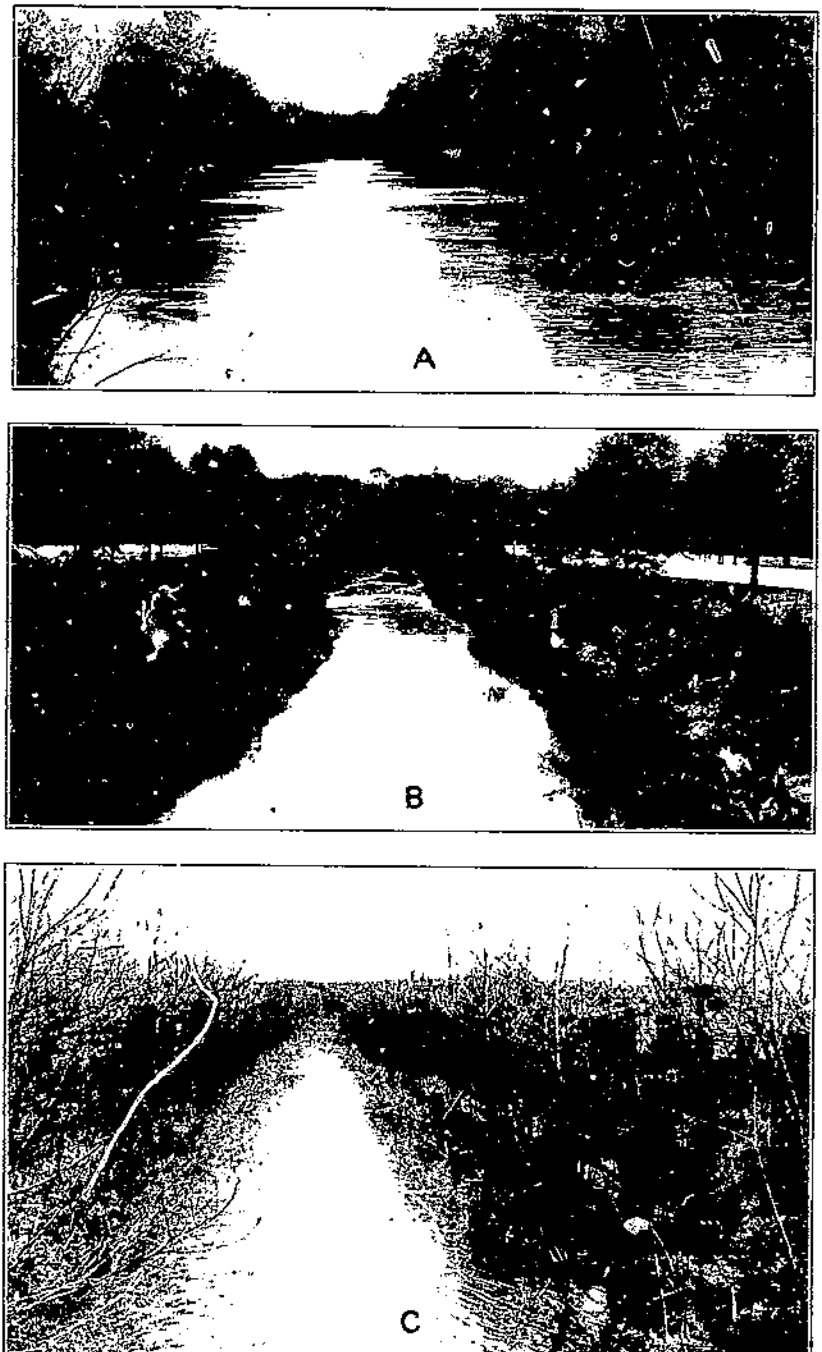
A view of this natural river channel taken in November, 1926, is shown in Plate 24, A. The bottom and lower side slopes were in very good condition at the time of making the measurements given in Table 9. The upper side slopes are covered with trees varying from 6 to 30 inches in diameter. At extremely high stages, limestone outcroppings are encountered on both banks. There were no very large variations in the size of the channel (fig. 20, A); an average cross section is shown in Figure 19, A.

Table 9 shows not much variation in the values of n except for the highest stage. This higher value is attributed to the greater amount of branches and foliage encountered at this stage. It is believed that if there were no growth on the banks, the value of n for this straight course of the Embarrass River would be about 0.025.

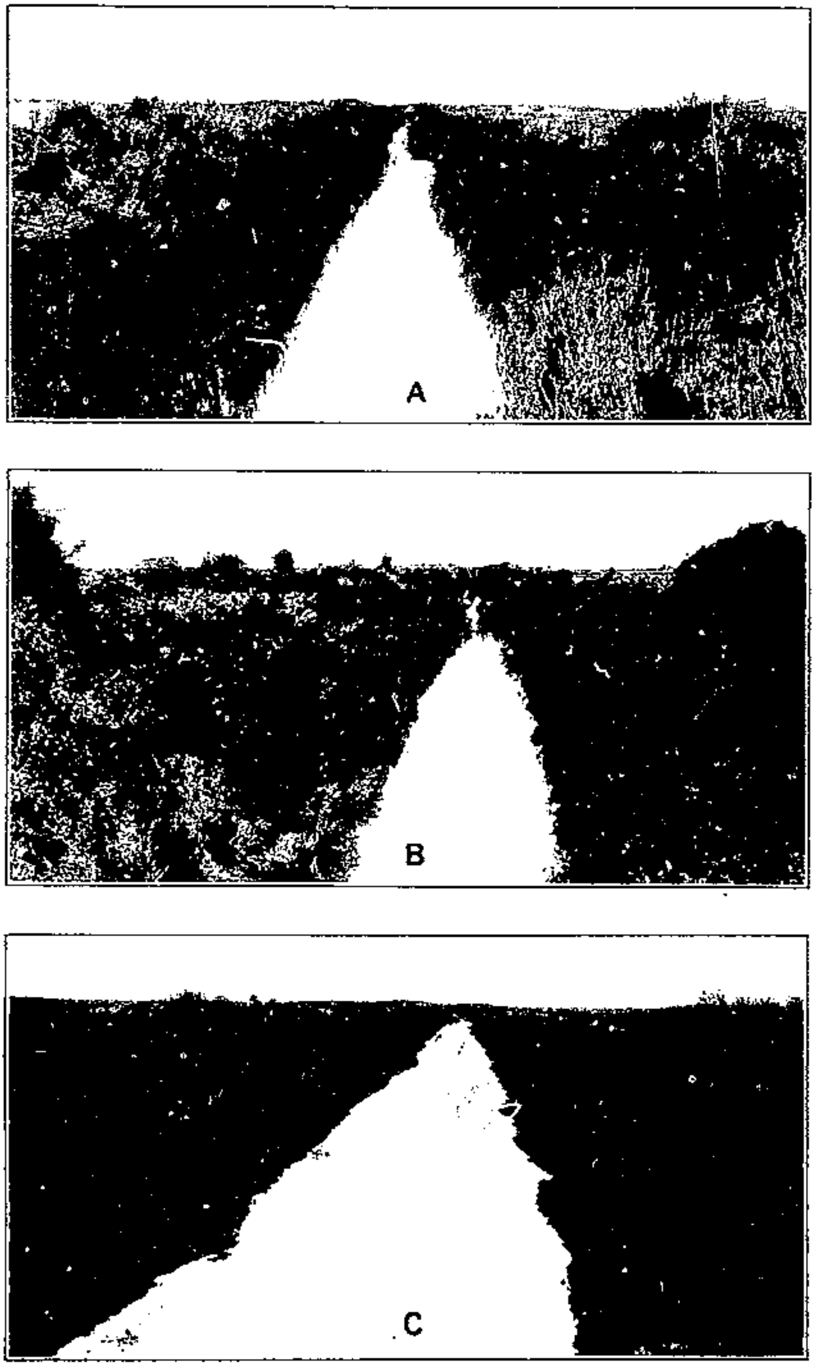
LAKE FORK SPECIAL DITCH

Gagings of this ditch were made from a single-span steel private bridge about 3 miles east of Bement, Ill. The slope course was straight, the upper end being about 300 feet below the bridge and just below the outlet of a large tile drain. Conditions were favorable for accurate slope and discharge measurements.

Numerous measurements were made on this channel under widely varying conditions during 1924, 1925, and 1926 . (See measurements 8 to 31 in Table 9.) When the first measurements were made, the sides of the channel were covered with a very dense growth of bushy willows and some poplar sprouts. (Pls. 25, A, and 25, B.) The channel was cleared out during the fall of 1925 (pl. 25, C), but by the fall of 1926 the growth in the channel was about the same as in 1924. The willows on the right bank did not cover the slope quite so thoroughly as in 1924, but they had been replaced in part by large stalky weeds which apparently offered about the same resistance to flow. Except for a silt bar about midway the length of the course, the bottom was in fairly good condition. Variations in the size of the cross section along the slope course were small, expecially for medium to high stages. (Fig. 20, B.) The average cross section is shown in Figure 19, B.



A, Embarrass River, near Charleston, Ill., looking up slope course, November, 1926; B, West Branch of Salt Fork dredged channel, near Urbana, Ill., looking up cleared slope course, July, 1924; C, West Branch of Salt Fork dredged channel, near Urbana, Ill., looking down uncleared slope course, April, 1925. (See Table 9)



Lake Fork special dredged channel, near Bement, Ill. A, Looking up slope course, April, 1925, vegetation without foliage; B, same view as A, above, in July, 1924, vegetation with summer foliage; C, same view as A, above, in November, 1925; channel had been cleared but a short time previously. (See Table 9)

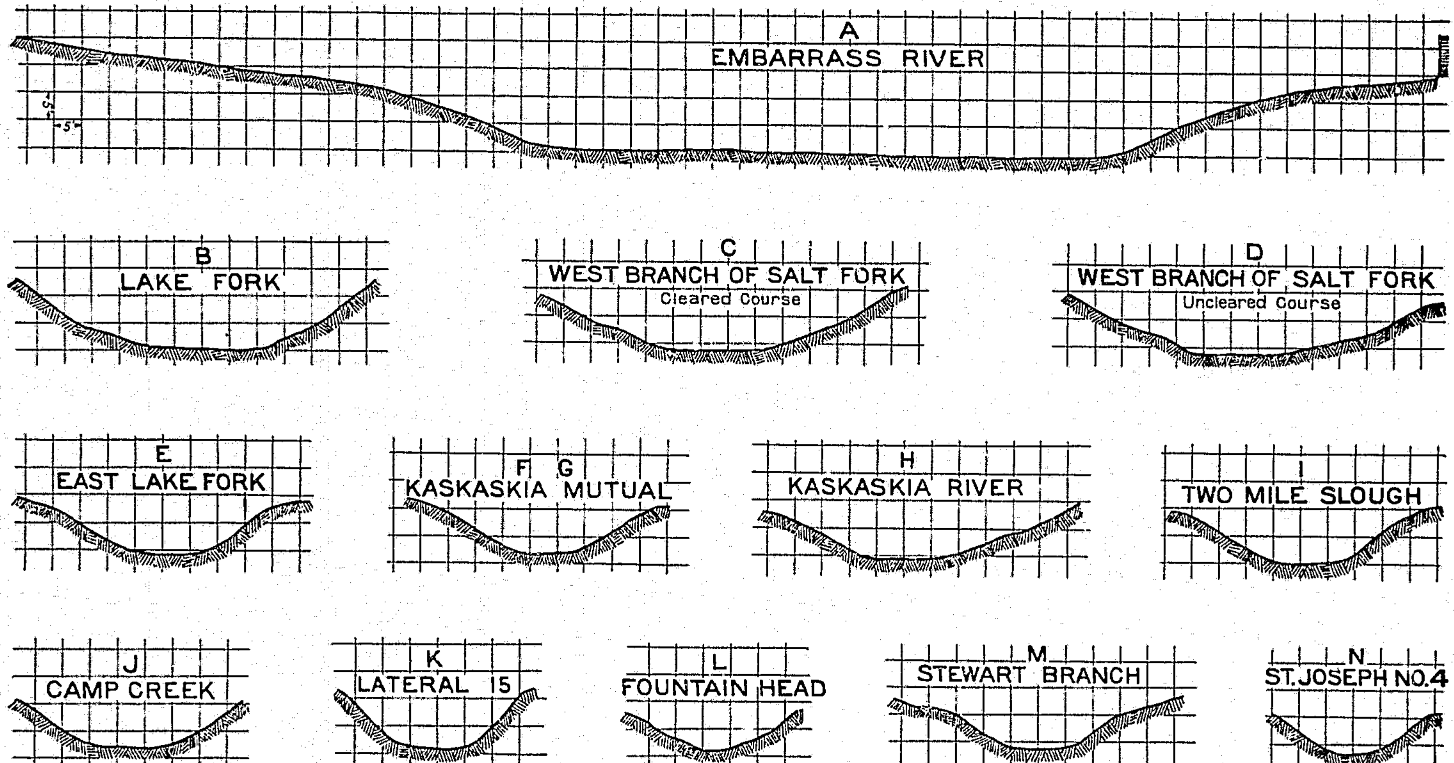


FIGURE 19.—Average cross sections of channels for experiments in central Illinois

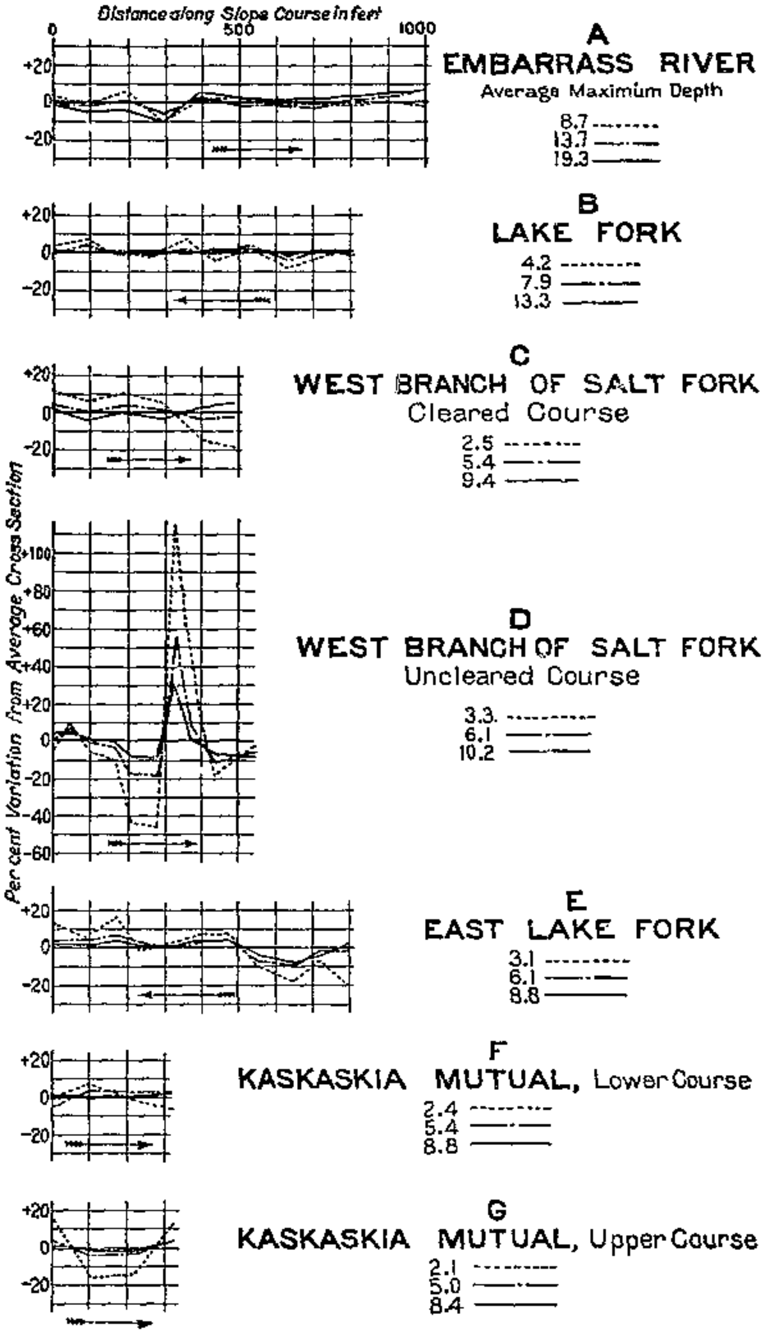
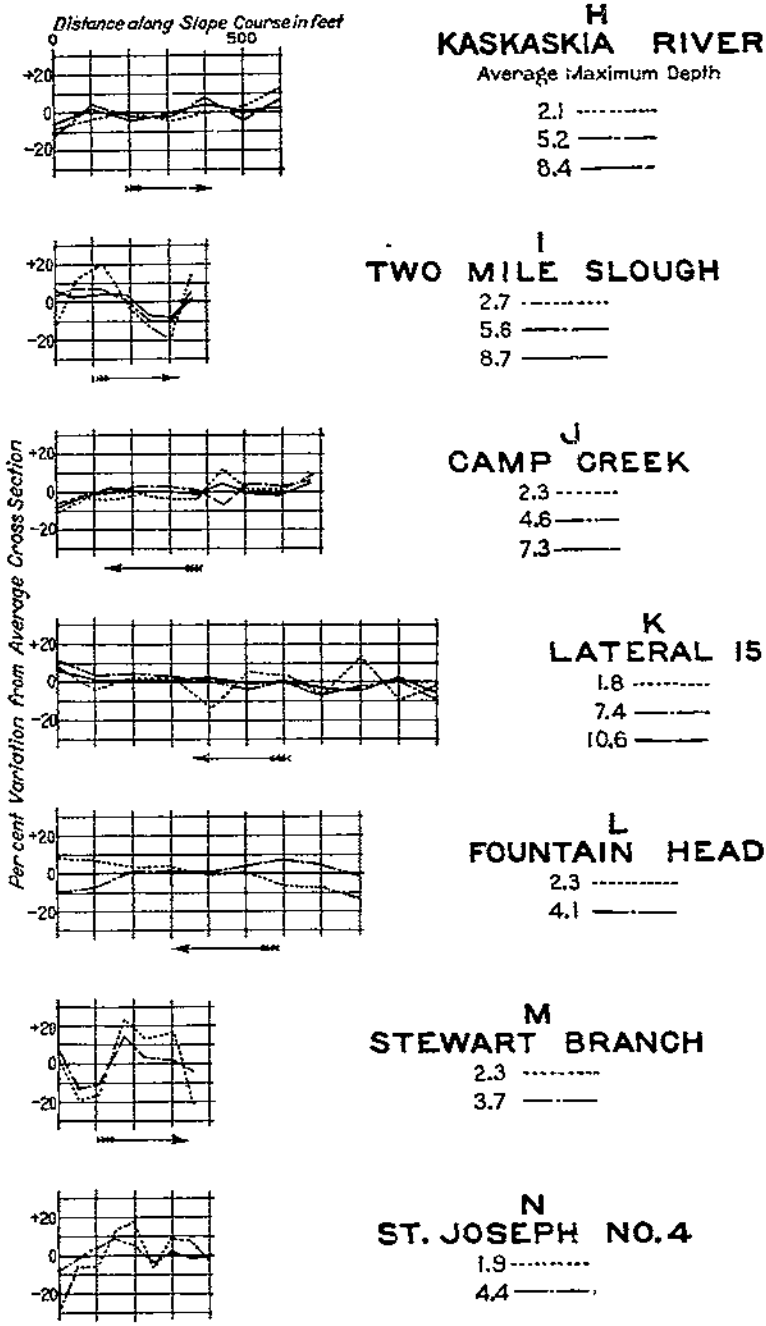


FIGURE 20.—Graphs for experiments in central Illinois showing per cent variation



from average cross-sectional area for all cross sections along slope courses

The measurements on this channel are grouped under three heads: (1) Winter and spring conditions for uncleared channel, (2) summer and fall conditions for uncleared channel, and (3) winter and spring conditions for cleared channel. Measurements 12, 13, and 16, made in June, 1924, are placed with winter and spring conditions because the water remained so high during the early part of that year that complete leafing out of the willows did not occur before these measurements were made. Measurements 19 and 20, made in October, 1926, are placed in this group because they were made after a protracted period of high water in September which stood over the willows until the leaves decayed and fell off; conditions then were similar to what would be found during the winter season.

Comparison of the values obtained under summer and fall conditions with those under winter and spring conditions, for similar stages in the uncleared channel, shows that foliage in the summer and fall greatly increases the roughness coefficient n. Comparison of the discharges, or of the values of the Chezy coefficient C, for similar stages shows to what extent the discharge capacity of a channel may be reduced by foliage. Comparison of the values of n, or of the discharges for the cleared and the uncleared channel, shows also that a large increase in capacity can be obtained by simply clearing the channel. The cost of clearing out this channel was insignificant as compared with the crop losses sustained by the farmers because of the tardy removal of the excess water after every heavy rain.

WEST BRANCH OF SALT FORK

Gagings were made from the North Broadway Street Bridge in Urbana, Ill. The slope was measured on a straight cleared course 480 feet long above the bridge, and on a straight uncleared course 550 feet long below the bridge. The section was fairly good for accurate discharge measurements, but at times the accuracy was affected to some extent by floating débris which interfered with current meter operations.

A view of the cleared course is shown in Plate 24, B. The average cross section is shown in Figure 19, C. There were no large variations in size along this course for medium to high stages. (Fig. 20, C.) In Table 9, measurements 32 to 49, it is seen that the values of n obtained for summer and fall conditions are somewhat larger than those for winter and spring conditions. This difference is due principally to the growth of grass in the channel during the early summer. The comparatively low value of n obtained in measurement 45 made in August, 1924, can be explained by the fact that the water had remained fairly high during the early part of that summer and prevented as luxuriant a growth of grass as developed in 1925 and 1926.

A view of the uncleared course is shown in Plate 24, C. The average cross section and the variation in cross section are shown in Figures 19, D and 20, D. Seasonal changes do not seem to have had any decided effect on this course. (See measurements 50 to 67 in Table 9.) Probably this is because the larger growth shaded the channel so that there was not much grass and weeds in the lower part or on the side slopes, while most of the foliage on the trees was above the water for most stages. At the highest stage, the flow encountered a greater amount of branches, which doubtless caused the comparatively high value then obtained for n. The condition of the channel varied somewhat from time to time, which is believed to account for the small differences in values of n obtained for nearly similar stages. For instance, measurement 53 was made after an extended period of high water and the comparatively low value of n was probably due to the washing away of leaves from the small willows and the flushing out of many obstructions which a lesser flood would not have dislodged.

EAST LAKE FORK

Gagings of this channel were made during the years 1925 and 1926. The highway bridge near the east limits of the town of Ivesdale was used as a gaging station. Only fairly accurate measurements of discharge were obtained, as there was some still water on both sides of the gaging section. The lower end of the slope course was located about 400 feet above the gaging station in order to avoid an undesirable curve in the channel. The course was straight, 800 feet in length. There was a rather gradual increase in cross sectional area from the lower to the upper end. (Fig. 20, E.) An average of the measured cross sections is shown in Figure 19, E.

The condition of this channel when the measurements were made in March, 1925 (Nos. 68 to 71 in Table 9), is shown in Plate 26, A. The channel had been cleared during the winter of 1924–25, and no new growth had started. As can be seen in the view, there were dead weeds and stubble on the side slopes. During the following summer, a new growth of willows and box elders sprang up in the channel. Measurements were made after the leaves had fallen off the first season's growth, and a decided increase in the value of n was obtained. (Nos. 72 to 74 in Table 9.) Measurements were made also after two summers' growth and before the leaves had fallen off. (Nos. 75 to 78 in Table 9.) These showed still higher values of n than the second group of measurements, due to the dense foliage on the vegetation. (See Plate 26, B, for view of channel in July, 1927.) On comparing measurements 70 and 75, made for the same stage of water, it is seen that the discharge was reduced from 152 second-feet in the newly cleared channel to 64 second-feet only 18 months later, although the slope was a third greater.

KASKASKIA MUTUAL DITCH

Measurements were made on this ditch during the years 1924, 1925, and 1926. The discharge was measured at the Illinois Traction System bridge about 1 mile east of Bondville, Ill., where there was a very good gaging section. The slope was measured on two fairly straight courses, each 330 feet long, just below the bridge. There was very little variation in the cross-sectional areas for medium and high stages along either course. (Figs. 20, F and 20, G.) An average cross section of the two courses in shown in Figure 19, F.

Plate 27 shows two views of the lower course, one taken when there was no foliage on the trees and the other when the trees were in full leaf. The trees consist of willow, box elder, and poplar. Their dense foliage shaded the channel so that there was very little undergrowth such as weeds and grass, except on the right bank for distances aggregating about one-half the length of the slope course. In these intervals there were large stalky weeds, together with a few bushy willows. The bottom for about three-fourths the length of the course was covered during the summer months with a water weed resembling the ordinary smartweed. (Pl. 27, B.) The growth in this channel had not been cleared out since about 1910.

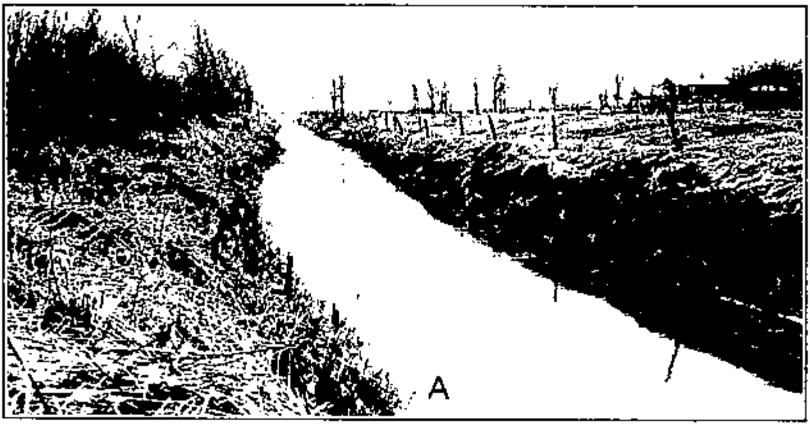
There are no measurements for making really satisfactory comparison of winter and spring conditions with summer and fall conditions, owing to the differences in stages of water. Numbers 81 and 85 (Table 9) give almost the same value for *n*. Perhaps the increase in sprouts and branches during the intervening 18 months just compensated, in this instance, for the lack of foliage at the later measurement. Little foliage was encountered by the water at low stages, owing to the dense shade and to pasturing, and only a moderate amount at medium stages, which accounts for the fairly regular increase in the value of *n* with the stage of water. Values of *n* obtained in the fall of 1926 are notably higher than those obtained in 1924, showing the effect of two years' additional growth of vegetation.

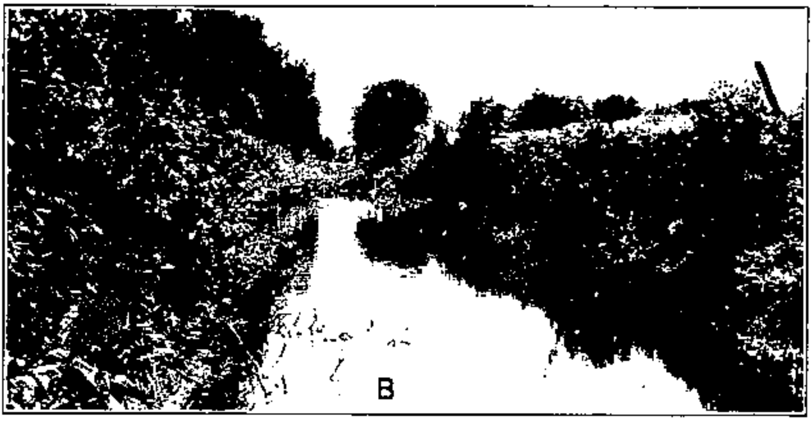
The chief difference between the upper and lower slope courses is the small amount of water weed in the former. As a result, lower values of *n* were obtained in the upper course at the low stages of water. The tree growth differs only in that the trees in the upper course are somewhat smaller and more numerous than in the lower course. (Pl. 27, C.) As on the lower course, the determinations of the value of *n* do not furnish a good comparison of winter and spring conditions with summer and fall conditions. Nos. 94 and 98 in Table 9 agree much as Nos. 81 and 85 on the lower course, probably for the same reason. Comparison of Nos. 93 and 97 seems to show the effect of the early summer growth of vegetation. The increase in the values of *n* from the summer of 1924 to 1926 is even greater than on the lower course.

KASKASKIA RIVER DITCH

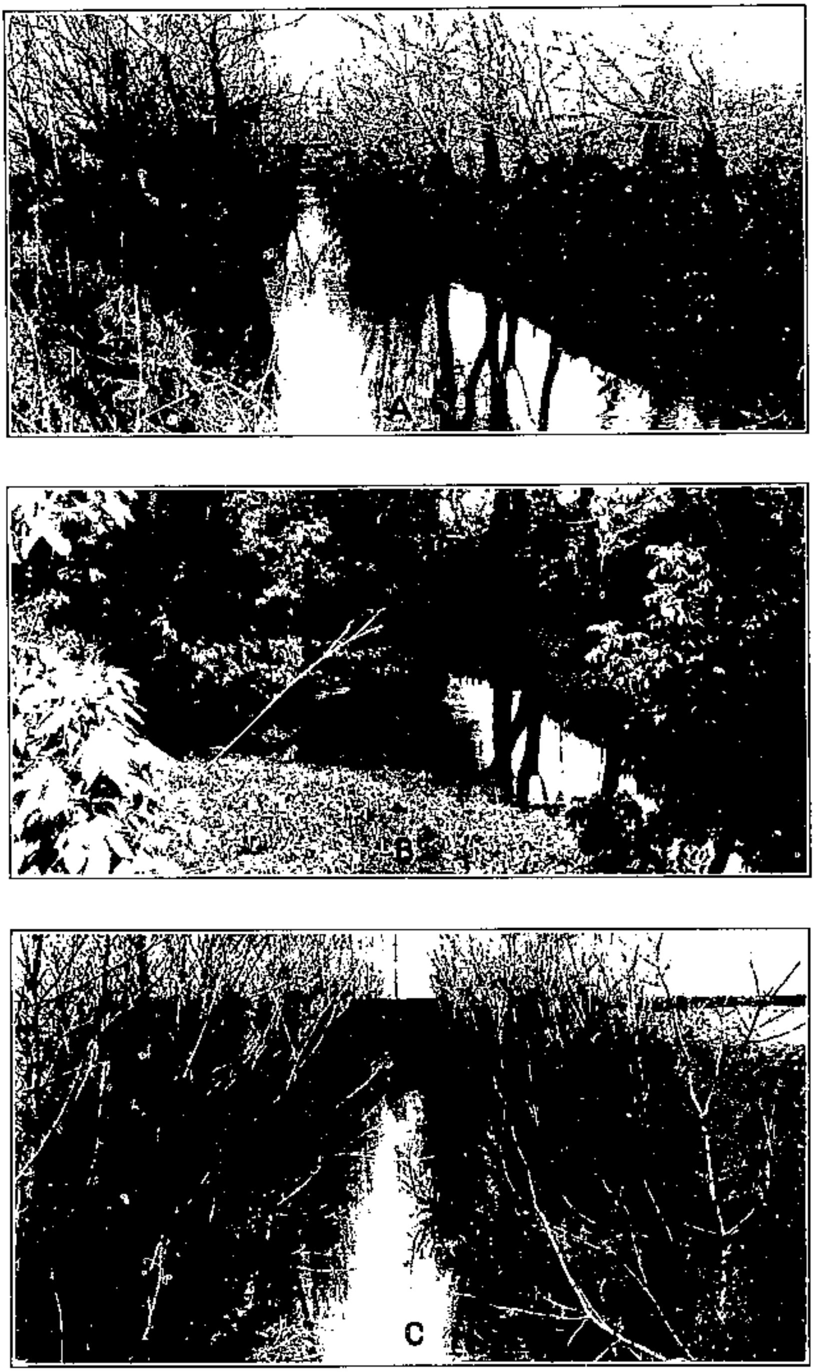
The Wabash Railroad bridge three-fourths of a mile west of Sadorus was used as a gaging station for this ditch. The slope course was 600 feet long and rather crooked and was located below the gaging station. Although the bridge made an angle of about 78° with the direction of flow, the gaging section was quite satisfactory, and it is believed that reliable measurements of both discharge and slope were obtained.

A view of the channel is shown in Plate 26, C. The average cross section and the variation in area are shown in Figures 19, H and 20, H. This channel is generally cleared out every two years, so there is practically no large growth in it. It was cleared out in September, 1925, shortly before the first gagings were made. (Nos. 108 to 110 in Table 9.) It will be noted that the values of *n* obtained for these first measurements are very low, as would be expected for a newly cleared channel. Comparison of these values with those obtained just one year later (Nos. 112 to 117) discloses a noticeable increase due to one year's growth of vegetation. The bottom part of the channel was in good condition, as vegetation does not grow on the steeper parts of the lower side slopes. This condition and the hard slippery clay in the lower part of the channel are responsible for the lower values of *n* obtained at low stages of flow. As the stage increases, more stalky weeds and bushy willows are encountered and the value of *n* increases, as may be seen from measurements 111 to 117.

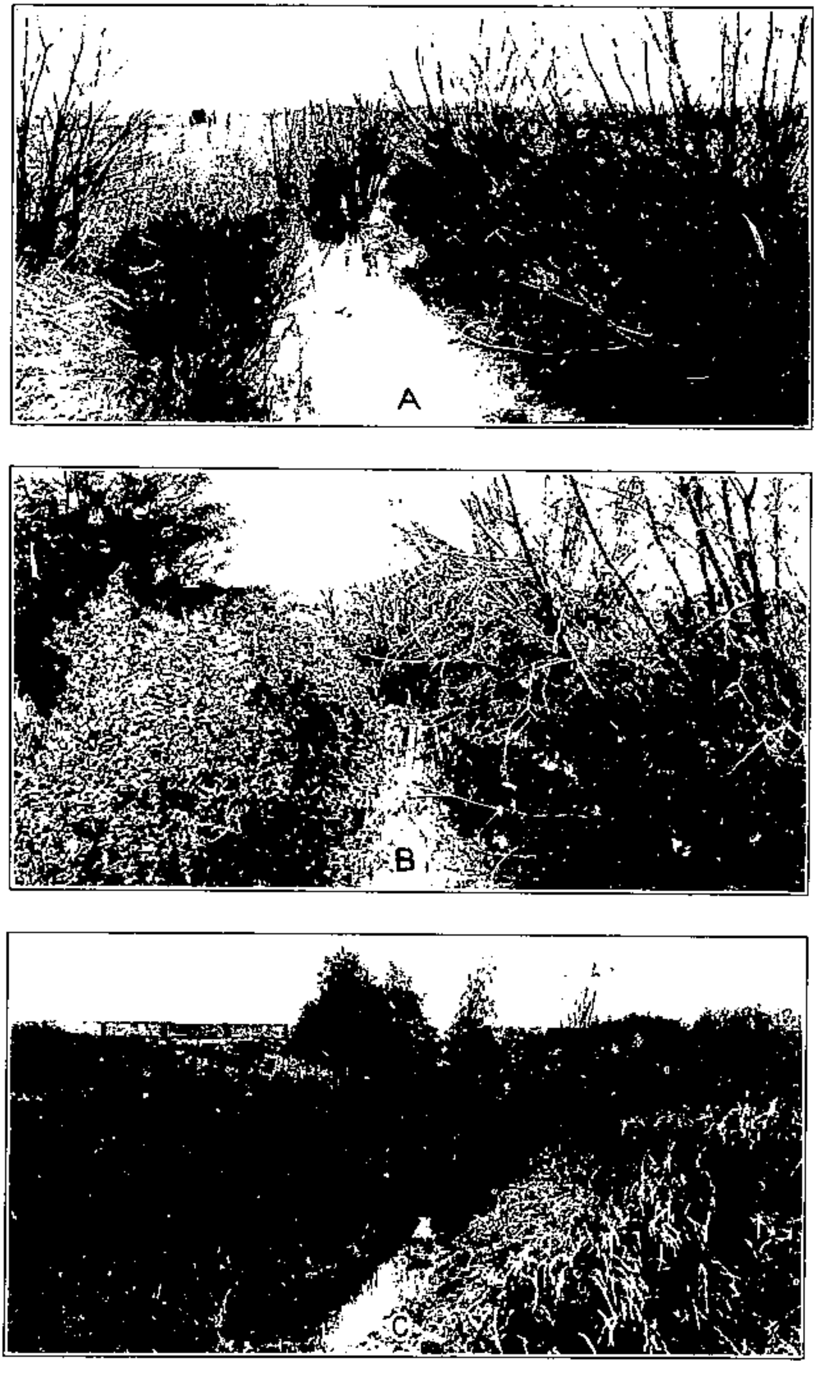




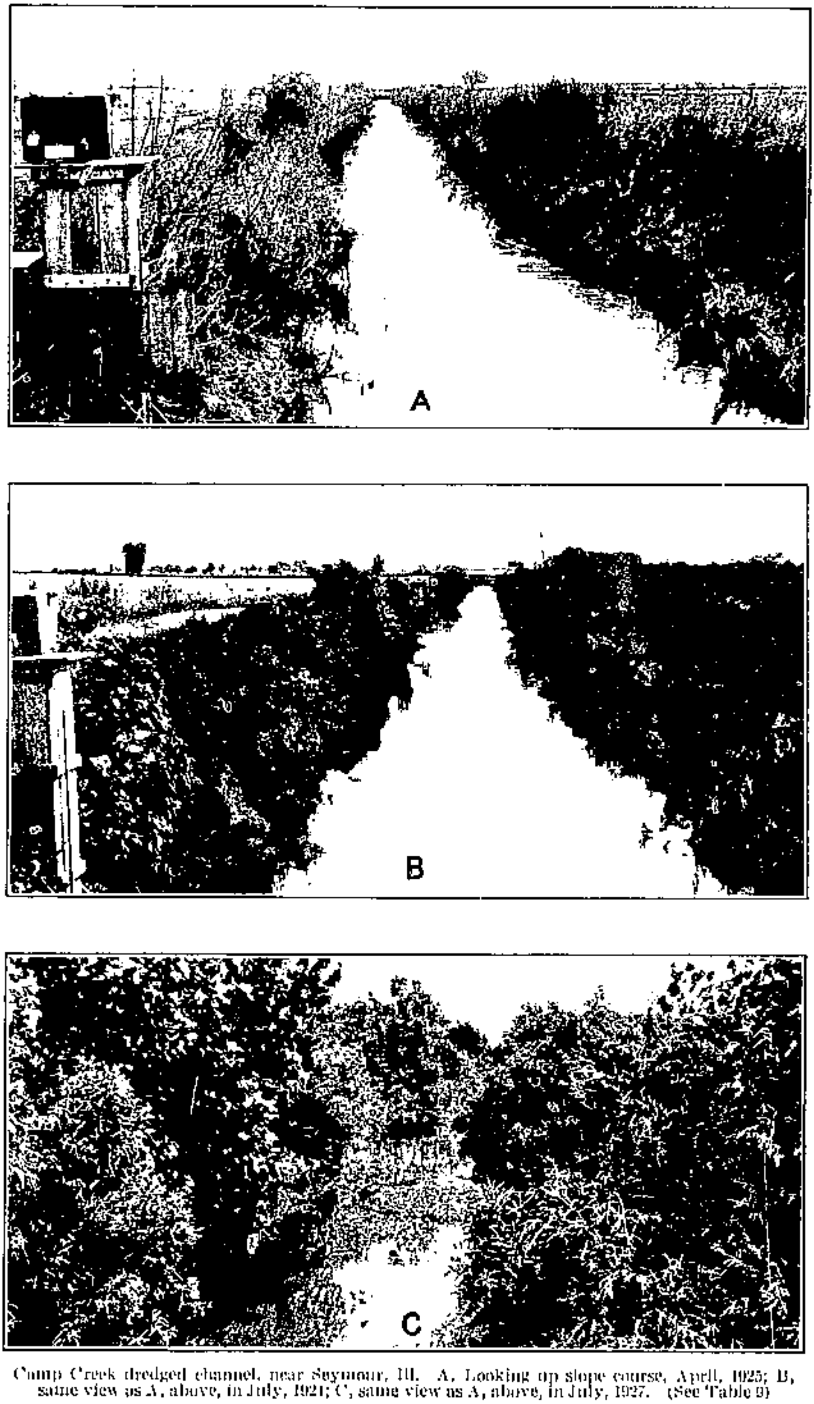
A, East Lake Fork dredged channel, near Ivesdale, Ill., looking up slope course, April, 1925; B, same view as A, above, in July, 1927; C, Kaskaskia River dredged channel, near Sadorus, Ill., looking down slope course, May, 1926. (See Table 9)



Kaskaskia mutual dredged channel, near Bondville, Ill. A, Looking up lower slope course, April, 1925; B, same view as A, above, in July, 1927; C, looking up upper slope course, April, 1925. (See Table 9)



A, Two Mile Slough dredged channel, near Sadorus, Ill., looking down slope course, April, 1925; B, same view as A, above, in October, 1926; C, Stewart Branch dredged channel, near Champaign, Ill., looking up slope course, October, 1926. (See Table 9)



Camp Creek dredged channel, near Seymour, Ill. A, Looking up slope course, April, 1925; B, same view as A, above, in July, 1926; C, same view as A, above, in July, 1927. (See Table 9)

TWO MILE SLOUGH

Gagings of Two Mile Slough were made from the concrete highway bridge about 1½ miles east of Sadorus. A short distance downstream from this bridge a straight slope course 360 feet long was laid out. Fairly accurate slope and discharge measurements were secured.

Plate 28 shows two views of the channel, one when there was no foliage on the vegetation and the other when the vegetation was in full leaf. The average cross section is shown in Figure 19, I. Figure 20, I shows that there were rather large variations in the cross section at low stages of flow but only moderate variations at medium to high stages. This channel had not been cleared since 1921 and was in very bad condition when these measurements were made. At low stages the thread of the stream wandered from side to side, on account of silt bars in the channel, some of which were covered with a water weed.

All the values of n obtained for this course are unusually high. (Nos. 118 to 131 in Table 9.) This undoubtedly is due to the bars and willow growth in the bottom of the channel. In general, these values increase with the stage of water, owing to the increase in amount of branches and foliage encountered by the flow. Number 118 is much lower than the others, probably because of the slippery clay of the ditch bottom and lower part of the side slopes, and because of the absence of weeds at that season. It will be noted, as for other channels, that the summer and fall measurements gave much higher values for n than the winter and spring measurements, particularly at high stages. Unquestionably this is because of foliage conditions.

CAMP CREEK

Gagings of this channel were made from a private single-span bridge, a few hundred feet north of the concrete highway about three-fourths of a mile west of Seymour, Ill. The slope course was straight, 661 feet long, and located just above the bridge. It is believed that quite accurate slope and discharge measurements were obtained. There was very little variation in the size of the cross section along the slope course. (Fig. 20, J.) The average cross section is shown in Figure 19, J.

Three views of this channel are shown in Plate 29. Its condition grew steadily worse during the period of the investigations. The channel was cleared during the winter of 1923–24, not long before the first measurements were made in April, 1924, but considerable growth had sprung up when the summer measurements were made two months later. By the summer of 1926 the bottom of the channel was covered with a dense growth of water weed and the side slopes were covered with a thicket of bushy willows, vines, and a few small poplar trees.

All the measurements under winter conditions were made at lower stages than any of the summer measurements (Table 9), when there was no foliage on the vegetation and no water weed in the bottom of the channel. Therefore the lower values obtained for n were to be expected. A comparison of the values obtained for n in 1924 and 1926 shows the large effect of the growth of vegetation in the channel.

LATERAL DITCH NO. 15

The single-span highway bridge about 1½ miles directly east of Bement, Ill., was used as a gaging station. A good gaging section was obtained here, and, although the bridge made an angle of about 85° with the direction of flow, it is believed that very accurate discharge measurements were secured. The slope was measured on a straight course 1,000 feet long, above the bridge. The shape of the cross section of the channel (fig. 19, K) was uniform throughout the length of the slope course; the size varied little except for very low stages. (Fig. 20, K.)

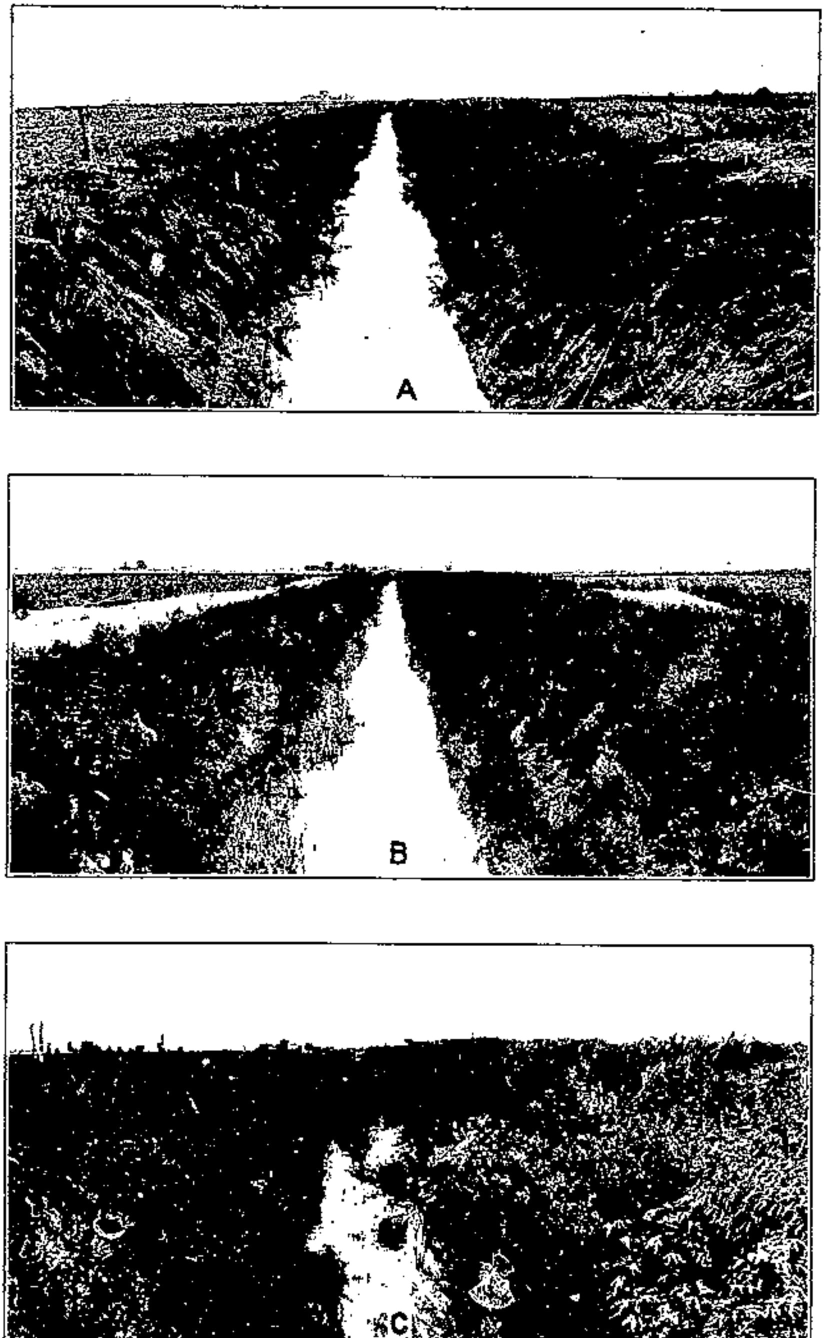
Three views of this channel are shown in Plate 30. This channel was redredged in 1922, and since then no vegetation had been cleared out. Until the spring of 1925 it was still in comparatively good condition; but after that time its condition grew rapidly worse, as shown by the view taken in July, 1927. During the summer of 1925, a dense growth of cat-tails appeared in the channel. They died in the fall, and most of them were washed away soon after the measurement on November 10 was made. The growth reappeared in greater profusion in 1926 and was washed away about September 15, before the last measurements were made. There were very few cat-tails in this channel in 1927; probably because of the shade from the heavy growth of willows.

The measurements on this channel are shown as Nos. 141 to 155 in Table 9. Comparatively low values of n were obtained in the spring of 1925. One year later considerably higher values were obtained, due to the growth of bushy willows in the channel. The summer and fall measurements, before the cat-tails were washed out, gave the highest values of n; the effect of the cat-tails in retarding flow may be inferred from a comparison of the last measurements with those made earlier in September, 1926. In this channel, the value of n was found generally to increase with a decrease in the depth of flow, probably because most of the vegetation was in the lower part of the channel. The soil on the upper side slopes crumbled and sloughed off, preventing much growth there.

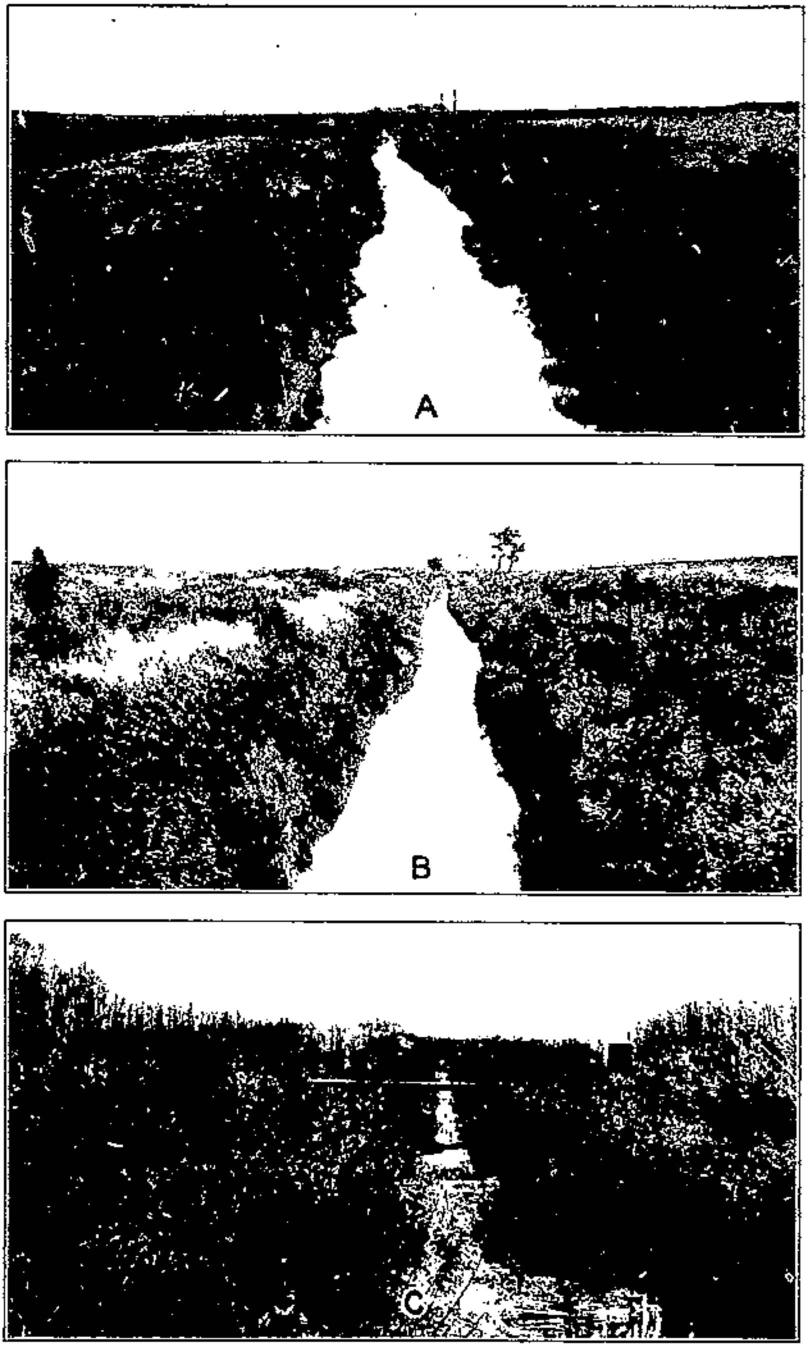
FOUNTAIN HEAD

Measurements of discharge in this channel were made from the concrete bridge on State Highway No. 10, about 2 miles west of Champaign, Ill. Although the bridge makes an angle of about 80° with the direction of flow, it is believed that fairly accurate gagings were obtained. The conditions were most favorable for accurate slope measurements, on a straight course 800 feet long above the bridge. There was a somewhat gradual increase in cross-sectional area for low stages, and a decrease for medium stages, along the slope course. (Figs. 19, L and 20, L.) Plate 31 shows two views of the channel. There were no willows or other trees in this channel, and the growth of weeds and grass which appears on the side slopes during the summer dries up and is broken off and flushed out during the winter.

No measurements for high stages were obtained on this channel. Water always stands to a depth of 1½ to 2 feet in this slope course, due to a low dam of rocks a short distance below the lower end of the course. This prevents the growth of vegetation in the bottom



Lateral Ditch No. 15, near Bement, Ill. A, Looking up slope course, April, 1925; B, same view as A, above, in July, 1924; C, same view as A, above, in July, 1927. (See Table 9)



A, Fountain Head dredged channel, near Champaign, Ill., looking up slope course, April, 1925; B, same view as A, above, in July, 1924; C, St. Joseph Township Ditch No. 4, near Mayview, Ill., looking down slope course, October, 1926. (See Table 9) of the channel, and with the rather slippery, waxy clay on the bottom accounts for the low value of n for measurement 156 (Table 9), made during an extreme low stage of flow. On account of vegetation in the summer and fall months, higher values of n were obtained then than during the winter and spring months when there were only a few dry weeds in the channel.

STEWART BRANCH

Gagings of this channel were made from a specially constructed footbridge a short distance east of the Illinois Central Railroad and about 1 mile north of that railroad's shops near Champaign, Ill. The slope measurements were made on a slightly crooked course of channel, near the center of which was a bend of about 15°. The course was 360 feet in length, located just below the footbridge. It is believed that quite accurate slope and discharge measurements were obtained on this ditch. A view of the channel is shown in Plate 28, C, taken during October, 1926. This ditch had been neglected since it was dug about 1890, so it was in very bad condition. There are rather abrupt and irregular variations in the cross-sectional area. (Figs. 19, M and 20, M.)

Measurements were made only for low and medium stages. As would be expected from the condition of the channel, very high values of n were obtained. When measurements 162 and 166 were made (see Table 9), the channel was in somewhat better condition than at the time of the other three measurements, because the vegetation had started to decay after being submerged by high water about September 4, and much of this decayed vegetation was flushed out by the high water about September 9.

ST. JOSEPH TOWNSHIP DITCH NO. 4

A specially constructed footbridge was used as a gaging station on this channel. It was located about 200 feet below a large tile which discharges into the upper end of this ditch, about 2 miles east of Mayview, Ill. The slope course was straight and 400 feet long, just below this footbridge. Satisfactory discharge and slope measurements were obtained. Variations in the cross-sectional area were rather abrupt but not very large. (Figs. 19, N and 20, N.)

The channel was in very bad condition, as shown by the view (pl. 31, C) taken a few weeks after the measurements were made. A thick growth of bushy willows extended throughout the length of the course, and there was some grass on the upper part of the side slopes. Only two measurements were made (Nos. 167 and 168 in Table 9), at medium stages and when the growth was in full leaf. As would be expected, comparatively large values of n were obtained. Without foliage, n would be considerably less for this channel.

DISCUSSION OF ILLINOIS EXPERIMENTS

The results of these experiments clearly indicate that annual clearing is a necessity in this section of the country and similar flat-prairie sections. Vegetation springs up rapidly where the soil is very fertile and the velocity of the water is low, conditions conducive to the rapid growth of vegetation from seed. East Lake Fork and Kaskaskia River ditches are cleared out every two years, but their condition after one year indicates that clearing every two years is not sufficient to keep them in good condition. The channel of the Lake Fork ditch was cleared during the fall of 1925, and values of n ranging from 0.030 to 0.032 were obtained during the following winter months, but measurements made during the following September for about similar stages, after one summer's growth of vegetation gave values of n ranging from 0.075 to 0.090. It is possible, however, that if the ditches were thoroughly cleared out every year the growth would not reappear as rapidly as when it is cleared only every two years.

Unless even more effective methods of maintenance than annual clearing are employed, it does not seem that the use of a value of n less than 0.040 would be justified in the design of channels. It is readily apparent from the results of the experiments that much higher values should be used where clearing every two years or less frequently is the general practice.

VARIATION OF n WITH STAGE IN CHANNEL

The results of these experiments show that generally the value of n decreases as the stage increases in channels free from vegetation. This was pointed out in an article in the Engineering News, February 24, 1916, by R. E. Horton,[6] as being true for natural river channels and was attributed to the fact that:

> In determining the coefficients of roughness in natural river channels the entire cross section as determined by soundings is taken into account, whereas if the cross section is irregular there may be pockets or holes in the bed of the stream containing slack water at lower stages, so that the full area of section is not effective. Similarly at low stages of a stream there is likely to be more or less fall that is not effective as slope and that does not contribute to producing velocity.

While the above is also generally true for dredged channels, yet these experiments show a great many exceptions, one of which is that of Mud Creek, where the values of n obtained were practically the same for all stages in the channel, owing to the fact that there was no appreciable amount of ineffective slope or cross section and practically no difference in the degree of roughness of the channel for different stages. (Pl. 1, C, and Table 1.) Another exception which shows the very reverse of the general statement above is that of Bogue Phalia dredged channel, where n increased for an increase of stage. This was due to the excellent condition of the lower part of the channel as compared with that of the upper part. (Pl. 3, A, and Table 2.)

Vegetation in a channel affects the variation in value of n with stage in various ways. If the vegetation consists principally of small trees and tall bushes, n generally begins increasing at the stage where the water reaches the spreading branches. The increase in the value of n is greater in the summer when the branches are full of foliage than in the winter, as illustrated by the results obtained for ditch No. 18 in Arkansas. (Table 7.) Where the vegetation consists of small growth such as weeds, low bushes, grasses, and short willows that cover the side slopes to the edge of low water, there is generally not much change in n for a change in stage, as was found for Cummins Lake ditch in Arkansas. (Table 7.) In some channels that have a fairly large low-water flow, the lower part of the channel is often free from

[6] HORTON, R. E. SOME BETTER KUTTER'S FORMULA COEFFICIENTS. Engin. News 75: 373–374. 1916

vegetation and a lower value of n is found for low than for high stages. (See results for Kaskaskia River ditch, Table 9.) Lower values of n are also obtained for low stages in channels where the vegetation consists of fairly large trees, such as in the channel of Kaskaskia mutual ditch in Illinois. (Table 9.) In this instance it is believed that the absence of small growth at low stages was due to the dense shade afforded by the trees.

MAINTENANCE

The results of these experiments show conclusively that systematic annual clearing is, as a general rule, indispensable if a drainage ditch is to be kept in a state of high hydraulic efficiency. Small ditches draining small watersheds require more attention than large ditches draining large watersheds, and ditches in comparatively flat country, such as central Illinois and the Delta of Mississippi and Arkansas, require more attention than ditches in country with rolling and hilly topography where the watercourses have greater fall. Large ditches with hilly watersheds, such as South Forked Deer River at Roberts, Tenn., and Boyer River at Missouri Valley, Iowa, are generally self-maintaining because there is nearly always a fairly large low-water flow which prevents growth on the bottom and the lower part of the side slopes, and there is generally sufficient erosion and caving to prevent growth on the upper part of the side slopes. Large ditches in flat country, such as Bogue Phalia ditch in Mississippi and ditch No. 43 in Cypress Creek drainage district in Arkansas, do not as a rule require much maintenance because there is nearly always a fairly large low-water flow and, even though the fall is small, the hydraulic radius is large and there is generally sufficient velocity to keep the channel in fairly good condition.

It is the comparatively small ditch in a flat country that requires most attention. Such ditches often go dry during the summer, and thus afford a good opportunity for vegetation to spring up from seed on the bottom of the ditch. The more fertile the soil, the more rapid and rank the growth. As the fall along the ditch is small, the velocity is unable to produce erosion, but generally permits the deposit of rich silt pregnant with plant seed, which produces growth at the first opportunity. The small ditches in the Delta of Arkansas and Mississippi, and especially the small ditches in central Illinois, exemplify these conditions. In the latter region, East Lake Fork and Kaskaskia River ditches are cleared out every two years but are choked with growth by the end of the first year, while the condition of Lake Fork ditch less than one year after clearing would seem to indicate that even annual removal of brush and weeds might not keep ditches in this section in satisfactory condition. However, it is possible that if these ditches were cleared every year, and attention given to removing or killing the roots of trees and large brush, the new growth would develop more slowly than it does under present practice.

APPLICATION OF RESULTS

It is impossible to describe with absolute accuracy the conditions existing in a channel, such as degree of regularity, amount and nature of obstructions and vegetation, and uniformity of cross section. Consequently it is impossible to formulate definite rules to govern one in choosing the proper value of n for any particular channel. It is believed that views, together with complete descriptions of channels for which the values of n have been determined, afford the best means of arriving at the proper value of n to employ for any particular channel. This applies especially to existing channels where it is desired to ascertain the capacity.

In order to determine the capacity of a proposed dredged channel it is necessary to assume anticipated conditions of channel. As is readily seen from the results of these experiments, values of n for dredged channels vary greatly, depending principally upon irregularities of side slopes and cross section due to erosion, caving banks, or faulty construction; upon obstructions and growth in the channel due to lack of maintenance; and, under certain conditions, upon the effect of a lining of silt in the channel. In most cases where erosion takes place in a newly constructed and well-finished dredged channel, the roughness coefficient increases, but the capacity of the channel as a rule also increases, since the enlarged cross section more than offsets the effect of the increased roughness coefficient. In some instances practically no difference in capacity in a newly dredged channel may result from erosion, after a certain amount of erosion has taken place, as was found to be the case for the experiments conducted on North Forked Deer River near Trenton, Tenn. (Table 3).

CONCLUSIONS

A careful study of the results of these experiments suggests the following conclusions:

That a deposit of slick, slimy silt on the sides and bottom of a channel greatly reduces frictional resistance to flow. (See results for Allen and Willow Creeks in Table 4.)

That the clearing of perennial growth from a channel will greatly increase its capacity. (See results for Old Town Creek in Table 1 and Lake Fork special ditch in Table 9.)

That the growth of grass and weeds in a channel during the summer greatly decreases its capacity. (See results of experiments for North Carolina in Table 5.)

That the accumulation of drift, trees, logs, and other obstructions in a channel greatly decreases its capacity. (See results for South Forked Deer River channel at Campbell's levee road in Table 3.)

That after a certain amount of erosion has taken place in a channel, further erosion does not necessarily increase the roughness of the perimeter. (See results for North Forked Deer River in Table 3.)

That the roughness coefficient n is appreciably higher for a roughly dredged channel than for a smoothly dredged one. (See results for the South Forked Deer River at Jackson and Roberts, in Table 3.)

That ordinarily a dredged channel quickly deteriorates in hydraulic efficiency unless systematically maintained. (See results of experiments in Arkansas and Illinois in Tables 7 and 9.)

That abrupt variations in cross section play an important part in reducing the hydraulic efficiency of a channel. (Compare Figures 2, 4, 6, 9, 11, 13, 15, 18, and 20 with values of n in the tables.)

RECOMMENDATIONS FOR DESIGN

Tabulated values of the roughness coefficient n in Kutter's formula, shown in Table 10, are recommended for use in computing the capacity of drainage channels of the conditions described:

TABLE 10.—*Values of n recommended for use in designing drainage ditches*

n	Description of channel	Example
0.025	Large channel in rolling country, with high velocity and sufficient low-water flow to prevent rapid growth of vegetation; slick silt lining perimeter; maintenance.[1]	Boyer River at Missouri Valley, Iowa. (Table 4.)
.030	Large channel in rolling country, with sufficient low-water flow to prevent rapid growth of vegetation; moderate erosion; maintenance.[1]	South Forked Deer River at Roberts, Tenn. (Table 3.)
.030	Large channel in flat country, with fairly large low-water flow; no appreciable erosion; annual clearing.	Bogue Phalia near Helm, Miss. (Table 2.)
.035	Small channel in rolling country, with small low-water flow; erosion sufficient to cause some irregularities; maintenance.[1]	Huggins Creek near Finger, Tenn. (Table 3.)
.035	Small channel in flat country, with insufficient low-water flow to prevent rapid growth of vegetation in lower part of channel; annual clearing.	Cummins Lake ditch near Gould, Ark. (Table 7.)
.035	Large channel with high velocity and large low-water flow; rapid erosion causing large irregularities; no vegetation.	Excavated channel in floodway, Little River Drainage District, Mo. (Table 8.)
.040	Small channel in flat country, with very fertile loamy soil conducive to rapid growth of vegetation; very small low-water flow, or dry in summer; annual clearing.	Lateral ditch No. 15 near Bement, Ill. (Table 9.)

[1] By "maintenance" is meant that the ditch is to be kept in good condition by clearing out growth and obstructions as often as found necessary, generally every 2 or 3 years.

In computing the capacity of an existing channel the value of n chosen should, whenever possible, be based upon a comparison of the conditions in the existing channel with the conditions of channels for which values of n have been determined. The comparisons are best made by actual inspections, but when such are impracticable, good views and careful descriptions of the channels for which the coefficient has been determined are next in value, and are more dependable than any general classification. In designing a new or improved channel, the condition that will be maintained must be assumed according to local circumstances, and the value of n be chosen accordingly.

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