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TECHNICAL BULLETIN No. 184 — JUNE, 1930

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EROSION AND SILTING OF DREDGED DRAINAGE DITCHES

By C. E. RAMSER

Senior Drainage Engineer, Division of Agricultural Engineering, Bureau of Public Roads

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INTRODUCTION

It is a matter of considerable importance to a drainage engineer to be able to foretell whether silting or erosion will occur in a drainage channel. Satisfactory and economical drainage often depends upon the accuracy of his prediction. For instance, if silting is expected it may be advisable to employ preventive measures such as sedimentation basins or check dams, thus obviating the necessity of redredging the channel later at great expense. If erosion in a channel is anticipated, it may be desirable to employ means to prevent it, or to take advantage of it by digging, at a comparatively low cost, a ditch smaller than is actually needed and depending upon the erosive action of the water to enlarge the ditch to the required capacity.

In many drainage enterprises a knowledge of the effects of silting and erosion has been gained only through costly experience. A considerable part of the main outlet ditch of a large drainage district in the Missouri River bottoms in eastern Nebraska was filled within a few weeks, and the crops on a large area were destroyed by the deposit of sediment contributed by a number of upland tributary streams. This ditch was cleaned out at considerable expense, and further silting prevented by providing 18 settling basins and one short diversion floodway.

A large channel in the main diversion floodway of a drainage district in Missouri was constructed close to one of the floodway levees for economy in handling the levee material. Erosion soon began to undermine the levee in places and seriously threatened it in others, so that costly protection works and the construction of a new levee in places, farther back from the channel, were imperative in order to avert disastrous floods. A foreknowledge of the possibilities of erosion and silting in these two instances would have rendered possible a substantial reduction in the ultimate cost of the projects.

There are a number of drainage districts in this country in which a considerable saving in the cost has been effected by constructing a ditch of inadequate size and allowing it to erode to the required size. There are some ditches where advantage could have been taken of the work of erosion with great saving to the landowners. In one instance in western Tennessee an engineer, foreseeing the probable effect of erosion, did not attempt to provide a ditch large enough for satisfactory drainage at the start. Most of the land in this district was in timber, and by the time a large portion of it was cleared and ready for cultivation the ditch had enlarged through erosion and satisfactory drainage prevailed.

During the investigations reported in this bulletin, measurements and observations were made between 1913 and 1921 on 22 dredged drainage ditches in Mississippi, Tennessee, and Iowa. The information presented consists of cross-sectional and hydraulic measurements and results of observation of all conditions that influence the erosion and silting of ditches. In these studies the writer has been particularly impressed with the fact that the measurements of the cross-sectional area and fall of a channel alone do not afford adequate information for a full story of erosion and silting, and in the following pages an effort is made to point out evidences of other factors that enter into the problem. It is believed that the results of these investigations will assist the engineer in making predictions as to probable erosion and silting in ditches so that drainage improvements can be planned accordingly.

RELATION OF VELOCITY TO EROSION AND SILTING

The erosive power of a stream varies as the square of the velocity. Theoretically, the maximum size of particle (as measured by the diameter) which can be transported by a current, assuming bodies of similar shape and substance, varies as the square of the velocity, and their weights (assuming equal volumes) as the sixth power of the velocity. However, it has been found by experiment that the weights vary more nearly as the fifth power of the velocity. From these general laws it is apparent that slight variations in the velocity of a stream may materially change its erosive and transporting capacity, and that the nonsilting velocity varies with the weight of the silt particles.

Clay soils are characterized by considerable cohesion among the particles and they present greater resistance to erosion than do sandy or silty soils. Excepting very sandy soils it is generally true that a soil that can be eroded can also be transported by the same current. Although clay soils are more difficult to erode than sandy soils, yet after being worn off the clay particles are more easily transported than the sandy particles. Observations show that little erosion of alluvial clay soil occurs where the velocity is much less than 3 feet per second. In some instances the velocity is not sufficient to erode the banks but is enough to pick up and carry away material that has caved into the channel, and in this way the enlargement of the channels takes place. The greatest erosion in a channel occurs in connection with the maximum velocity. Hence, it is important that the probable maximum velocity be known in predicting the likelihood of erosion in a channel. In the absence of backwater conditions the maximum velocity in a channel occurs with the highest stage.

Silt is transported by a stream in two ways: (1) In suspension and (2) by rolling along the bottom. It is believed, however, that rolling plays a minor part in the movement of silt in most drainage ditches. The power of a stream to transport silt in suspension is derived from the eddies at the bed. The upward component of these eddies tends to prevent the suspended particles from sinking, and the greater the velocity of flow the greater is this upward component. The eddies generated on 1 square foot of the bed of a stream hold the silt in suspension in a vertical column above, extending to the surface of the water. With a given density of silt in the water, the longer this column the greater would be the velocity of the water required to support the silt. Hence, it is seen that a relation may exist between the velocity and the depth such that no silting in the channel takes place and for which, if it be already fully charged with silt, the water will not pick up and carry off more material. This velocity is known as the critical velocity. The relation is expressed by Kennedy in the equation.

$$V = CD^m = 0.84D^{0.64}$$

in which V = critical velocity in feet per second.
D = depth of water in feet.
C and m are constants depending upon the kind of silt.

The values $C = 0.84$ and $m = 0.64$ were found to be suitable for fine sand such as that found in the beds of rivers in the Punjab (India) shortly after they have left the hills. The curve representing this equation is shown in Figure 1. From this equation it is seen that in a nonsilting channel the velocity is independent of the width, but increases with the depth of the channel.

Column 8 of Tables 1, 2, and 3 (see p. 13) show velocities as taken from this curve corresponding to the depths of the different channels, and column 7 shows the velocities obtained by measurements for bank-full stages of the channels. These latter velocities are plotted in Figure 1, symbols being used to indicate whether erosion or silting occurs in the channels. It is seen from this figure that both erosion and silting took place in many of the channels and that silting occurred where the normal velocity was much greater than that obtained by the Kennedy formula for the particular depth. This may have been due either to difference in size of transported particles, or to the fact that the velocity in a channel at the time silting occurred was less than that under normal conditions of flow, although under normal conditions the velocity might have agreed closely with the velocity as obtained by Kennedy's formula. The size of the particles transported by the different streams was not determined, and sufficient data are not available to determine definitely what happened.

Ordinarily the velocity in a drainage channel varies greatly during rapidly rising and falling stages and where affected by backwater. The growth of vegetation tends to promote silting and to prevent erosion, irrespective of the depth-velocity relation. Caving of banks

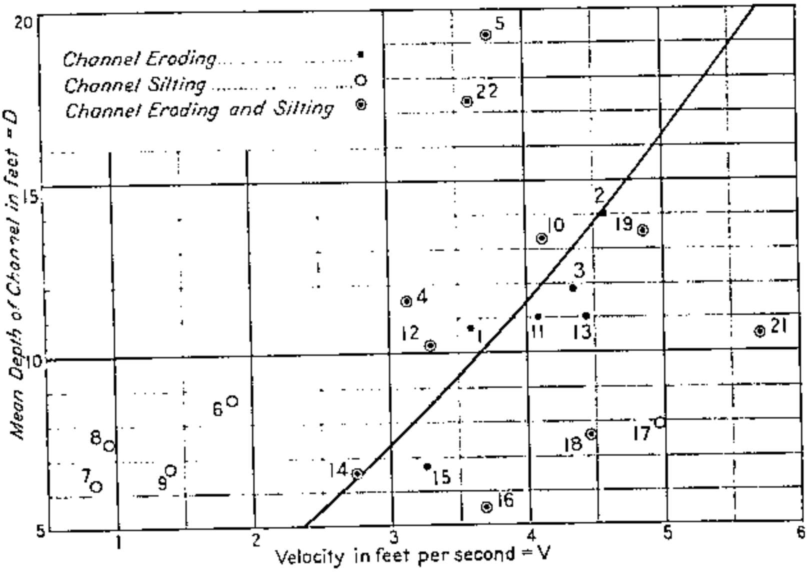


FIGURE 1. Relation between Kennedy's velocities as indicated by curve, and measured velocities in channels at bank-full stages. The numbers near the plotted points refer to the numbers of the ditches given in Tables 1, 2, and 3

often occurs where the velocity is insufficient to carry away caved-in material. Most of the ditches investigated were affected by one or more of the above conditions, so that it would be unreasonable to expect conditions as regards erosion and silting to conform to the Kennedy formula. Even though the conditions of caving banks and growth of vegetation were eliminated by proper side slopes and systematic maintenance, it is not believed that Kennedy's formula would be applicable to the design of drainage channels where there are generally such great variations in the velocity.

VELOCITY DUE TO THREE FACTORS

A common mistake in predicting the probability of erosion or silting in a drainage channel is to base the estimate upon the fall of the channel alone. Though it is true that fall is the positive factor that produces velocity through the action of gravity, yet there are two other factors that exert a decided effect upon the velocity. These are the hydraulic radius and the resistance to flow caused by the condition of the channel, as represented by the value of n in Kutter's formula; the larger the value of n, the greater the resistance to flow. The velocity varies with these factors about as given in the formula,

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

where V = velocity in feet per second,

C is a constant representing the condition of the channel (the greater the resistance to flow the smaller is C),

$$C = \frac{\frac{1.811}{n} + 41.66 + \frac{0.00281}{s}}{1 + \left(41.66 + \frac{0.00281}{s}\right)\frac{n}{\sqrt{R}}}$$

where R = the hydraulic radius,

s = slope of the water surface.

The term " n " in the above formula is a measure of all the conditions in a channel that tend to retard the flow.

An inspection of the values given in the tables shows that the highest velocities are not always in the channels with the greatest fall. For instance, in comparing the channel of the South Forked Deer River at Roberts, Tenn. (Table 2, p. 14), which has a fall of 1.32 feet per mile, with that of Cypress Creek with a fall of 10.1 feet per mile, it is seen that the former has the greater velocity due to its larger hydraulic radius and less resistance to flow as represented by the values of n. The hydraulic radius is equal to the cross-sectional area divided by the wetted perimeter. Thus it is apparent that a large, deep ditch would have a greater hydraulic radius than would a small, shallow one. For example, the hydraulic radii of the channels of the South Forked Deer River at Roberts and the Bogue Phalia may be compared with those of Cypress Creek and Pecan Bayou as given in Tables 1 and 2.

A comparison of the channel of Willow Creek in Iowa with that of Bogue Hasty in Mississippi, where the hydraulic radii are, respectively, 5.35 and 6.1, the fall, 0.86 and 0.83 foot per mile, the roughness coefficient n, 0.0128 and 0.0353, and the velocities, 4.46 and 1.86 feet per second, shows that the hydraulic radii and fall do not differ greatly; the considerable difference in the velocities must therefore be due to the large difference in the roughness coefficient n. (Tables 1 and 3.)

CONDITIONS AFFECTING EROSION AND SILTING IN A CHANNEL

VEGETATION

Vegetation in a channel checks or greatly reduces erosion and promotes silting. A heavy mat of grass, high weeds, cattails, saplings, or small shrubs protects the soil from the erosive action of the water, and the roots hold the soil in place. The vegetation tends to retard the flow, thus reducing the velocity and thereby the erosive action of the water. Erosion had practically ceased in the channel of Coonewah Creek in Mississippi at the time of the last measurements when the side slopes and part of the bottom of the channel were covered with a heavy growth of grass. (Table 1.) The channel of Mud Creek in Mississippi is an instance where such growth has prevented rapid erosion such as occurred in Chawappah Creek, the channel of which was practically free of vegetation. Vegetation in the channels of Willow Creek and Allen Creek in Iowa promoted silting and prevented erosion since the soil and velocities were practically the same as in the channel of the Boyer River at Missouri Valley where considerable erosion and not much silting occurred, there being comparatively little vegetation in the latter channel. To prevent permanent silting in these channels, or to reduce it to a minimum, the vegetation should be cleared out annually. Usually the velocity of flow and the consequent erosive action decrease with the age of the ditch on account of general deterioration caused chiefly by the growth of vegetation; therefore the greatest velocity of flow for a given stage in a ditch, as well as the most rapid erosion, usually take place before vegetation is established.

CAVING AND SLOUGHING BANKS

In nearly all ditches where rapid enlargement occurs, this is largely the result of caving of the banks. This caving may be due to several causes. If the side slopes are dug at an angle greater than the angle of repose for the particular kind of soil, caving may take place caused by gravity alone. An example of this type of caving occurred shortly after construction in the channels of Twenty Mile, Chawappah, and Coonewah Creeks in Mississippi, where the side slopes were 1 on ½.

If the soil in the bank is saturated, the angle of repose is flatter than for drained soil. For this reason, in digging a ditch through marshland where the soil is saturated, it is advisable to lower the water in the ditch slowly so that the water has time to drain from the soil; otherwise, caving may result which will seriously damage the ditch. Openings should always be provided in spoil banks so that water will not be held back of them and the banks become saturated. Failure to do this has caused many ditches to cave.

A rather common practice in southwest Minnesota, in marshland having a gravelly subsoil, is first to dig a narrow ditch to drain out the soil and later to enlarge the ditch to the required size. Attempts to dig the ditch to the required size at the start dictated this practice because of the caving of banks and the filling of channels.

If the spoil banks are placed close to the edge of the ditch the tendency to cave is increased by the superimposed weight of the spoil banks which reduces the angle of repose. This practice has been common in western Iowa, and the rapid enlargement of the Boyer River ditch at both Missouri Valley and Dunlap was due largely to this cause, nearly all of the spoil banks of these ditches having caved into the channels. In an effort to prevent such caving into the channels of Allen and Willow Creeks, side slopes of about 1 on 2 were used. The widening of a channel by caving is greater for a deep than for a shallow channel since it is apparent that in the case of a deep ditch the angle of repose will intersect the ground surface at a greater distance from the edge of the bank. To this cause may be attributed, in part, the great widening of the channels of the Boyer River in Iowa, the South Forked Deer River at Roberts, Tenn., and the Bogue Phalia in Mississippi. Another cause of the caving of banks is undermining by erosion, the portion above the undermined section of the bank caving into the channel. It is obvious that where a combination of the foregoing causes of caving operates on the bank of a ditch the caving action is very rapid.

Sloughing of the banks is very common in the South where alternate freezing and thawing often occur several times during a single spring season. The freezing heaves the soil, and when thawing takes place the loosened soil moves down the slope and the first high water thereafter washes it away.

The tendency to cave is greater for some soils than for others, depending upon the angle of repose. Soils in which layers of sand are found are very susceptible to caving. Alluvial silt soils cave more readily than clay soils. The side slopes of all of the channels investigated were measured in order to determine about what slopes should be used for different types of soils. It was found that for strictly alluvial soils in the Mississippi and Missouri River bottoms in the States of Mississippi and Iowa the average of the side slopes measured was 1 on 2. Flatter slopes probably would be required where considerable sand is encountered or where the soil is an extremely fine silt. Measurements showed that the average side slope of ditches that drain upland areas in Iowa, Tennessee, and Mississippi was about 1 on 1½. The silty soils in these comparatively narrow bottoms are not so fine as those in the large river bottoms since they have been washed from near-by upland areas and carried off at relatively high velocities.

Material that caves into a channel is not always carried away but may settle to the bottom. This happens where the velocity is not sufficient to move the caved-in material, as was the case in some of the ditches in Bolivar County, Miss. In Figures 9 and 14 are shown cross sections of two ditches where caving took place. In the channel of the North Forked Deer River the velocity was 4.57 feet per second, sufficient to remove the caved-in material, while in the channel of West Bogue Hasty the velocity was but 0.93 foot per second, insufficient to remove the caved-in material which settled to the bottom. Practically all the material in the bottom of this channel came from the caving banks since the the entire watershed is flat land, and erosion is negligible. In some instances the mean velocity was high enough to transport the material if the bottom velocities were able to pick it up. Again, some banks cave into the channel as a solid mass held together by vegetation and roots which even water flowing at a high velocity fails to move. An example of this type of caving occurred in the channel of the Little Sioux River cut-off in Iowa. (Pl. 22 and fig. 23.) From the foregoing it is apparent that the caving of ditch banks may be the cause either of the enlargement or of the filling of a ditch.

BACKWATER

The effect of backwater is a marked reduction in the velocity of flow due to a decrease in the slope of the water surface caused by a high stage at the outlet of the channel. Where backwater occurs the velocity for any particular stage may vary widely. The maximum occurs when the outlet channel is at low stage, and the minimum when an extreme flood stage is in the outlet channel. Hence, it is apparent that the velocity may be such as to permit silting in the channel at one time and scouring at another. In addition to widening the channel, scouring may wash out much or all of the silt that has accumulated during backwater conditions. The Boyer River at Missouri Valley, Iowa, is a good example of this type of channel. Backwater resulting from fluctuations in its outlet channel (the Missouri River) happens frequently and has a very decided influence upon the deposition of silt in the channel. Where there is considerable vegetation in a channel, silt deposited during periods of backwater may not all be removed during times of high velocity, and the accumulated silt soon incapacitates the ditch. An example of this is the Allen Creek Channel near Missouri Valley, Iowa.

VARIATION IN WATER STAGES

Since the water supply of a drainage channel is dependent upon rainfall, and as the duration, intensity, and amount of rainfall are subject to extreme variations, it is obvious that the stages in the drainage channels will likewise be subject to wide variations, ranging from a stage a little above low water for light rains to one often several feet over the banks of the channel for heavy rains. Few drainage channels have been designed to carry the run-off from the heaviest rain. In general the velocity in a channel increases with the stage so that wide variations in velocity occur, the highest often being sufficient to cause erosion and the lowest to permit silting.

Often in the case of a channel running to full capacity with a high velocity and water fully charged with silt, the water supply is suddenly cut off by the cessation of rain; this results in the deposition of much silt during the rapidly falling stage. Under such conditions erosion may take place at the high stage and silting during the falling stages.

ENLARGEMENT OF CROSS SECTION

When, owing to erosion, a channel widens and the velocity is such as to carry in suspension all of the silt delivered to it, the channel will maintain its original depth until the velocity is so far reduced as to cause deposit of the charge of silt. As the channel widens the cross-sectional area increases so that the stage does not rise so high as formerly to remove the same quantity of water. As a result the hydraulic radius and the slope of the water surface are slightly reduced with an accompanying reduction in the velocity. Silting occurs and increases with each decrement of the velocity, and a gradual filling takes place, which keeps pace with the widening of the channel. The deposits of sediment in Twenty Mile and Chawappah Creeks in Mississippi probably were caused chiefly in this manner. (Figs. 3 and 4.) The same thing happened in the channel of the Boyer River at Dunlap and Missouri Valley, Iowa, but had not proceeded far at the time of the last cross-sectional measurements. (Figs. 20 and 21.)

SILT CHARGE IN STREAMS

The silt in a stream may be washed from the surface of the tributary watershed, or it may be picked up or eroded from the bed or sides of the channel. If the velocity is not sufficient to cause erosion or to pick up material that may cave into the channel, and if erosion from the watershed is negligible, the water will contain very little silt and there will be practically no silting or erosion in the channel. The channels of Pecan Bayou and East Bogue Hasty in Mississippi are instances where the foregoing conditions prevailed. If these same channels with their slight fall and low velocity drained upland areas, as is the case with the channels in Lee County, Miss., they would silt up rapidly.

The quantity of silt carried into channels from upland watersheds is exceedingly variable and depends largely upon the intensity of the rainfall and upon the susceptibility of the ground surface to erosion. If the land surface be protected from erosion, as by systems of good terraces, very little washing will result, and the streams will be practically free of silt. With the exception of the streams in Bolivar County, Miss., those mentioned in this bulletin were, during maximum floods, almost fully charged with silt eroded from the hilly portions of their watersheds. When more silt is contributed to a channel than the water can carry, the excess is deposited in its bed. An example of this type of silting is the Cypress Creek ditch in Tennessee which has a large fall and a fairly high velocity, but which was overloaded with silt washed from the comparatively steep hillsides.

VARIATION IN FALL OF CHANNELS

Other factors remaining the same, the velocity in a channel varies about as the square root of the fall. Hence, it is apparent that if the fall can be changed at will any desired velocity may be obtained. Advantage is taken of this fact in controlling erosion on some streams by building check dams across them at intervals to reduce the fall and thereby the velocity and the eroding power of the water. The same principle is applied to prevent silting in a channel. As is generally known, the fall of most channels decreases from the upper to the lower end of the watershed; sometimes changes in fall are very abrupt, but generally they are gradual. Other conditions being the same, the channel will carry more silt on the steeper than on the flatter grades, and where abrupt changes occur and for some distance below that point silting takes place until the balance between the silt carried and the velocity of the water is restored.

The inference should not be drawn from the above that the velocity in all streams where the fall decreases grows less as the stream approaches its mouth. Such is the case only when all other conditions affecting the velocity remain the same. For example, the velocity in the channel of the South Forked Deer River at Roberts, Tenn., was found to be higher than that of the South Forked Deer River above Roberts, at Jackson and at Henderson. Although the channel at Roberts has less fall than at either of the other points, it has a larger hydraulic radius and a lower value of n—both factors that tend to produce a higher velocity. Another example is the Bogue Phalia Channel in Mississippi as compared with the channel of Bogue Hasty, a tributary of the Bogue Phalia.

The most sudden variation in the fall of drainage channels usually takes place where a stream emerges from an area of rolling and hilly relief and enters the comparatively flat bottom lands of a large river such as the Missouri or the Mississippi. Silt at high velocities is brought down from the hilly areas and deposited in the bottom-land channels of low velocity. Such a condition exists where the channels of Allen and Willow Creeks emerge from the hills, and the condition is somewhat aggravated during times of backwater from the Missouri River. Where this condition requires too frequent cleaning out of a ditch it can be remedied by constructing sedimentation basins on the bottom land where the stream emerges from the hills as has been done on several streams in the Burt-Washington district in eastern Nebraska.

VOLUME OF RUN-OFF WATER

Other factors being the same, the total volume of water that runs off through a channel increases with the size of the watershed and the amount of rainfall. Where the rainfall is the same, stages in streams with large watersheds remain high for a longer period than do those in streams with small watersheds. Thus, high stages in the South Forked Deer River at Roberts, Tenn., with a watershed area of 704 square miles, continue usually several days, while in Cypress Creek at Bethel Springs, Tenn., with a watershed area of 6 square miles, they last only a few hours. It is therefore apparent that the time during which erosion and silting occur is much greater for a channel with a large watershed than for one with a small watershed, and this accounts for the fact that erosion is sometimes slower in a channel with a large fall and small watershed than in a channel with a slight fall and a large watershed.

In the case of channels with watersheds of the same size and similar characteristics, the greater erosion and silting will take place where the greater annual rainfall occurs, since, for instance, the length of time that high stages prevail in a ditch will be greater where the annual rainfall is 60 inches than where it is only 30 inches. This is one of the reasons why, other conditions being the same, erosion and silting progress more rapidly in the South than in the North, the frequency of floods being much less in the North on account of the lighter rainfall.

EFFECTS OF EROSION AND SILTING ON THE DISCHARGE CAPACITY OF A CHANNEL

The discharge capacity of a channel may be increased by erosion or decreased by silting. In column 9 of Tables 1, 2, and 3, opposite the mean velocities in column 7, are given discharges that were measured for bank-full stages. The other discharges in this column were computed upon the assumption that the value of n for each ditch remained the same as at the time the actual discharges were measured. Attention is particularly called to the fact that, even where there was no change in the value of n, an increase in cross-sectional area does not necessarily result in an increased discharge capacity since the hydraulic radius may decrease sufficiently, on account of silting, to offset the increased cross-sectional area caused by erosion. By reference to the tables it is seen that in many instances decided increases in discharge capacities took place where there was very little change in the value of *n*, judging from the condition of the channels shown in the photographs. Drainage conditions over the bottoms drained by Twenty Mile Creek in Mississippi and the North Forked Deer River in Tennessee improved greatly as a result of the increased discharge capacities of these channels. In both of these instances a considerable financial saving was effected by digging a channel smaller than was needed and allowing the action of erosion to enlarge it to the required size. It is true that, in adopting this practice, the benefit from erosion is not realized immediately. However, in the case of the North Forked Deer River, by the time a large part of the land was cleared and ready for cultivation the ditch had enlarged to adequate size.

On the other hand, silting may occur and decrease the discharge capacity of a ditch, as in the case of Cypress Creek near Bethel Springs, Tenn. This is very common where silt brought down by upland streams is deposited in channels extending through bottom land.

FIELD MEASUREMENTS

Preliminary to making the cross-sectional measurements of each stream, a length of channel was selected in which erosion and silting were typical. These courses ranged in length from 300 to more than 1,000 feet. Within each course from five to eight cross sections were made and these measurements were repeated at intervals of from one to eight years. The measurements were repeated once for some streams and twice for others.

At the time the first cross sections were made, measurements of the surface slope and velocity of flow were also made to determine the roughness coefficient, *n*, in Kutter's formula. The results of these latter experiments and the methods of making measurements are presented in Technical Bulletin 129.[1] However, some of the results are included in this bulletin to show the relation existing between silting and erosion, and the hydraulic elements in a channel.

COMPUTATIONS

The mean cross-sectional areas given in Tables 1 to 3 were determined in the following manner: The several cross sections along a course were plotted on cross-section paper; these were then superimposed so that the center lines and the water-surface lines for a bank-full stage coincided; a mean cross-section line was then determined for each set of measurements, and these were plotted as shown in Figures 2 to 23, inclusive, one over another as described above. Any change in the channels during the period of observation is thus evident. The original cross sections of the ditches, according to the engineer's specifications, are also plotted with the mean cross sections, but it should be remembered that a dredged section seldom conforms closely to the specified dimensions.

[1] RAMSER, C. E. FLOW OF WATER IN DRAINAGE CHANNELS. U. S. Dept. Agr. Tech. Bull. 129, 104 p., illus. 1929.

The water-surface line for bank-full stage was plotted on both the mean cross sections and the several measured cross sections. In cases where the spoil banks serve as levees this line was taken as level with the ground surface outside the levees. For that part of each mean cross section below the water-surface line the cross-sectional area, wetted perimeter, top width, and average depth, which thus represent the mean values in that course of the channel, were determined. The cross-sectional areas were measured with planimeter. The hydraulic radius for each mean section was computed by dividing the cross-sectional area by the wetted perimeter. Values of nonsilting velocities corresponding to the average maximum depths were taken from the curve representing Kennedy's formula. (Fig. 1.) Computations for values of *n* in Kutter's formula were made in the manner described in Technical Bulletin 129.

TABULATED RESULTS

Tables 1 to 3 show the hydraulic elements of the channels together with data relating to the changes in the channels due to erosion and silting. In most cases the cross-sectional area given as of the time the ditch was constructed is based upon the dimensions given in the engineer's specifications for the channel. Usually a ditch is dug a little wider and a little deeper than the specifications require, but it may be dug smaller. Consequently not much dependence can be placed upon these areas, and they are of little significance where only a slight change has taken place in the channel. Where a very great change has occurred, as in the Boyer River at Dunlap, Iowa, the probable error in the original area at construction would not be large enough to affect materially the percentage of change in the cross section.

In column 7 are given the mean velocities in the channels which were measured at about the time the cross-sectional measurements opposite which they are placed in the table were made, and in column 8 are shown the velocities corresponding to the average maximum depth for each channel as computed by Kennedy's formula.

Column 9 shows the discharges of the channels in cubic feet per second. The values given opposite the velocities (column 7) were obtained by actual gagings. The other values were computed by using the values of slope and *n*, which are given in columns 13 and 14, and which were determined at the time the gagings were made. The discharge values are given to show the effect of erosion or silting upon the discharge capacity of a channel provided no change in the roughness coefficient occurs.

The mean maximum depths and mean top widths of each channel are given in columns 10 and 11; these values indicate the changes in depth and width caused by erosion and silting. Column 12 shows the mean hydraulic radii, changes in which indicate variations in the hydraulic efficiencies of the channels, other factors remaining the same.

In column 15 are given the depths at which the water stood over the banks for floods during the season in which the discharge measurements were made.

TABLE 1.—*Data relating to changes in dredged drainage channels in Mississippi due to erosion and silting*

Stream	Stream No.	Reference No. of measurement	Watershed area	Date of measurement	Mean cross-sectional area	Mean normal velocity	Kennedy's nonsilting velocity	Discharge	Mean maximum depth	Mean top width	Mean hydraulic radius	Fall of water surface	Value of n Kutter's formula	Depth of flood stage over banks	Time elapsed between measurements: Reference No.	Time elapsed between measurements: Years	Time elapsed between measurements: Months	Per cent of change: Area	Per cent of change: Discharge	Change: Depth	Change: Top width
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
			Sq. mi.		*Sq. ft.*	*Ft. per sec.*	*Ft. per sec.*	*Cu. ft. per sec.*	*Feet*	*Feet*	*Feet*	*Ft. per mi.*		*Feet*						*Feet*	*Feet*
Mud Creek near Tupelo, Miss.	1	1	100	Jan., 1913	[1]220.0	3.60	3.82	794	11.0	30.0	5.6	2.1	0.0263	3.0							
		2		Mar., 1914	254.0			914	10.7	33.5	5.6				1 and 4	8	4	+54.0	+61.2	+1.6	+17.0
		3		Aug., 1918	306.2			1,221	11.8	40.5	6.5				2 and 4	7	2	+33.3	+40.0	+1.9	+13.5
		4		May, 1921	338.8			1,280	12.6	47.0	6.0										
Twenty Mile Creek near Baldwyn, Miss.	2	1	80	Jan., 1910	[1]175.0	4.57	4.47	611	10.0	25.0	5.0	6.1	.0440	3.0	1 and 3	8	7	+196.4	+293.0	−.2	+37.0
		2		Mar., 1913	384.5			1,758	14.0	44.8	7.2				2 and 3	5	5	+35.0	+36.6	−4.2	+17.2
		3		Aug., 1918	518.8			2,402	9.8	62.0	7.4										
Chawappah Creek near Shannon, Miss.	3	1	140	May, 1911	[1]165.0	4.34	4.07	582	11.0	20.0	4.9	4.9	.0385	2.0							
		2		Mar., 1913	312.0			1,354	11.8	39.5	6.6				1 and 4	10	0	+120.4	+150.5	−3.3	+36.5
		3		Aug., 1918	337.5			1,392	8.1	49.0	6.1				2 and 4	8	2	+16.6	+7.7	−4.1	+17.0
		4		May, 1921	363.8			1,456	7.7	56.5	5.9										
Coonewah Creek near Shannon, Miss.	4	1	56	May, 1909	[1]195.0	3.14	4.00	535	10.0	25.0	5.3	3.3	.0430	2.0	1 and 3	9	3	+84.2	+106.4	+1.9	+26.3
		2		Mar., 1913	309.0			970	11.5	39.2	6.4				2 and 3	5	5	+16.2	+13.9	+ .4	+12.1
		3		Aug., 1918	359.2			1,105	11.9	51.3	6.2										
Bogue Phalia near Helm, Miss	5	1	323	May, 1913	[1]1,036.0	3.74	5.67	3,489	14.0	88.0	10.5	1.03	.0313	0	1 and 3	8	0	+38.6	+53.3	+5.8	+19.4
		2		Jan., 1915	1,374.0			5,140	19.8	99.0	12.3				2 and 3	6	4	+4.5	+4.0	0	+8.4
		3		May, 1921	1,436.0			5,347	19.8	107.4	12.2										
Bogue Hasty near Shaw, Miss.	6	1	70	Sept., 1911	[1]360.0	1.86	3.36	668	8.0	50.0	6.1	.83	.0353	2.0	1 and 3	9	8	+5.3	+4.3	+1.2	+10.0
		2		Jan., 1915	373.5			694	8.7	57.0	6.1				2 and 3	6	4	+1.5	+ .4	+0.5	+3.0
		3		May, 1921	379.0			697	9.2	60.0	6.0										
Pecan Bayou near Shaw, Miss.	7	1	13	July, 1911	[1]90.0	.85	2.72	67	5.3	22.5	3.3	.41	.0395	3.0	1 and 3	9	10	+21.1	+31.3	+1.0	+3.5
		2		Nov., 1914	113.8			96	6.3	24.7	3.9				2 and 3	6	6	−4.2	−8.3	0	+1.3
		3		May, 1921	109.0			88	6.3	26.0	3.7										
West Bogue Hasty near Shaw, Miss.	8	1	24	May, 1911	[1]156.0	.93	3.05	125	6.0	32.0	4.2	.40	.0436	3.0	1 and 3	10	0	+33.6	+41.6	+1.0	+11.0
		2		Nov., 1914	203.8			189	7.5	35.8	5.0				2 and 3	6	6	+2.2	−6.3	− .5	+7.2
		3		May, 1921	208.3			177	7.0	43.0	4.5										
East Bogue Hasty near Shaw, Miss.	9	1	16	July, 1911	[1]91.0	1.39	2.84	116	5.5	21.0	3.5	1.31	.0430	3.0	1 and 3	9	10	+22.3	+22.4	+ .7	+7.0
		2		Nov., 1914	122.5			171	6.7	28.0	3.9				2 and 3	6	6	−9.2	−16.9	− .5	0
		3		May, 1921	111.3			142	6.2	28.0	3.5										

[1] Original cross sections at time of construction computed from dimensions of channels given in engineers' specifications. Not as much dependence can be placed upon these values as where measurements were made.

TABLE 2.—*Data relating to changes in dredged drainage channels in Tennessee due to erosion and silting*

Stream	Stream No.	Reference No. of measurement	Watershed area	Date of measurement	Mean cross-sectional area	Mean normal velocity	Kennedy's nonsilting velocity	Discharge	Mean maximum depth	Mean top width	Mean hydraulic radius	Fall of water surface	Value of n Kutter's formula	Depth of flood stage over banks	Time elapsed between measurements: Reference No.	Time elapsed between measurements: Years	Time elapsed between measurements: Months	Per cent of change: Area	Per cent of change: Discharge	Change: Depth	Change: Top width
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
			Sq. mi.		*Sq. ft.*	*Ft. per sec.*	*Ft. per sec.*	*Cu. ft. per sec.*	*Feet*	*Feet*	*Feet*	*Ft. per mi.*		*Feet*						*Feet*	*Feet*
South Forked Deer River near Roberts, Tenn.	10	1	704	Oct., 1915	[1] 500.0	4.12	4.30	1,880	10.0	55.0	7.4	1.32	0.0242	2.8	1 and 4	5	7	+92.1	+138.2	+4.7	+26.0
		2		Feb., 1916	653.6			2,691	13.3	63.0	8.5				2 and 4	5	3	+46.9	+66.2	+1.4	+18.0
		3		Aug., 1918	734.2			3,185	13.3	69.0	9.2										
		4		May, 1921	960.3			4,478	14.7	81.0	10.3										
South Forked Deer River near Jackson, Tenn.	11	1	563	Mar., 1916	[1] 400.0	4.09	3.90	1,620	10.0	45.0	7.0	2.82	.0322	2.0	1 and 3	2	5	+29.3	+44.6	+3.4	+8.3
		2		Jan., 1917	425.4			1,740	11.0	53.3	7.1				2 and 3	1	7	+21.6	+34.6	+2.4	0
		3		Aug., 1918	517.2			2,342	13.4	53.3	8.2										
South Forked Deer River near Henderson, Tenn.	12	1	205	Nov., 1915	[1] 189.0	3.30	3.72	547	7.0	34.0	4.8	1.70	.0268	2.5	1 and 4	5	6	+103.0	+156.5	+2.6	+15.8
		2		Apr., 1916	290.1			956	10.2	36.0	5.8				2 and 4	5	1	+32.2	+46.8	−.6	+13.8
		3		Aug., 1918	327.0			1,426	9.5	42.0	6.2										
		4		May, 1921	383.5			1,403	9.6	49.8	6.8										
North Forked Deer River near Trenton, Tenn.	13	1	93	May, 1915	[1] 221.0	4.57	3.90	883	8.0	36.0	5.3	2.75	.0265	.5	1 and 4	3	3	+101.2	+142.9	+3.4	+21.2
		2		Apr., 1916	331.0			1,512	11.2	42.0	6.6				2 and 4	2	4	+36.1	+41.8	+.2	+15.2
		3		Jan., 1917	402.4			1,838	11.0	55.0	6.6										
		4		Aug., 1918	450.7			2,111	11.4	57.2	7.0										
Huggins Creek near Finger, Tenn.	14	1	37	Oct., 1914	[1] 129.5	2.76	2.78	384	7.0	22.0	4.2	3.27	.0333	2.7	1 and 4	6	7	+20.9	+16.7	−.4	+13.7
		2		Apr., 1916	146.3			404	6.5	34.2	3.8				2 and 4	5	1	+7.0	+10.9	+.1	+1.5
		3		Aug., 1918	145.6			402	6.6	31.2	3.8										
		4		May, 1921	156.6			448	6.6	35.7	4.0										
Sugar Creek near Henderson, Tenn.	15	1	30	Nov., 1914	[1] 108.0	3.25	2.83	245	6.0	24.0	3.7	4.52	.0331	1.7	1 and 4	6	6	+33.8	+48.7	+1.2	+5.0
		2		Feb., 1916	122.9			530	6.7	27.0	3.8				2 and 4	5	3	+17.6	+28.2	+.5	+2.0
		3		Aug., 1918	134.6			473	6.8	27.3	4.2										
		4		May, 1921	144.5			513	7.2	29.0	4.3										
Cypress Creek near Bethel Springs, Tenn.	16	1	6	Dec., 1915	[1] 108.0	3.69	2.50	421	6.0	24.0	3.7	10.10	.0103	0	1 and 4	5	5	+4.2	−13.2	−1.6	+13.5
		2		Feb., 1916	105.3			361	5.5	33.0	3.1				2 and 4	5	3	+6.9	+1.9	−1.1	+4.5
		3		Aug., 1918	132.8			400	5.5	36.0	3.4										
		4		May, 1921	112.6			368	4.4	37.5	2.9										

[1] Original cross sections at time of construction computed from dimensions of channels given in engineers' specifications. Not as much dependence can be placed upon these values as where measurements were made.

TABLE 3.—*Data relating to changes in dredged drainage channels in Iowa due to erosion and silting*

Stream	Stream No.	Reference No. of measurement	Watershed area	Date of measurement	Mean cross sectional area	Mean normal velocity	Kennedy's nonsilting velocity	Discharge	Mean maximum depth	Mean top width	Mean hydraulic radius	Fall of water surface	Value of n Kutter's formula	Depth of flood stage over banks	Time elapsed between measurements: Reference No.	Years	Months	Per cent of change: Area	Per cent of change: Discharge	Change: Depth	Change: Top width
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
			Sq. mi.		*Sq. ft.*	*Ft. per sec.*	*Ft. per sec.*	*Cu. ft. per sec.*	*Feet*	*Feet*	*Feet*	*Ft. per mi.*		*Feet*						*Feet*	*Feet*
Allen Creek near Missouri Valley, Iowa.	17	2	59	June, 1917	218.5	4.95	3.15	1,082	7.9	41.2	4.60	1.73	0.0149	0	2 and 3	3	11	−20.9	−30.3	−1.1	0
		3		May, 1921	172.0			754	6.8	41.2	3.77										
Willow Creek near Missouri Valley, Iowa.	18	2	133	June, 1917	287.1	4.46	3.08	1,282	7.6	49.2	5.35	.86	.0128	0	2 and 3	3	11	+6.0	+5.8	+.8	+4.1
		3		May, 1921	304.5			1,356	8.4	53.3	5.31										
Boyer River near Missouri Valley, Iowa.	19	1	900	1910	[1] 444.0			1,865	12.0	49.0	7.55										
		2		Apr., 1916	785.1	4.87	4.43	3,773	14.9	73.4	9.34	.46	.0171	2.0	1 and 4	11		+117.0	+137.0	−.6	+55.5
		3		June, 1917	871.6			4,210	13.5	85.0	9.75				2 and 4	5	1	+22.8	+17.3	−3.5	+31.1
		4		May, 1921	966.3			4,427	11.4	104.5	8.68										
Boyer River near Dunlap, Iowa.	20	1	654	1910	[1] 312.0				12.0	32.0	6.67										
		2		Apr., 1916	1,097.0				18.4	87.8	11.17			0	1 and 4	11		+346.0		+4.9	+78.0
		3		June, 1917	1,231.0				18.3	91.5	11.94				2 and 4	5	1	+26.6		−1.4	+22.2
		4		May, 1921	1,389.0				16.9	110.0	11.48										
Pigeon Creek near Crescent, Iowa.	21	1	148		[1] 231.0			1,153	7.0	40.0	5.01										
		2		June, 1917	309.4	5.71	3.78	1,767	10.5	43.4	6.22	3.28	.0220	1.0	1 and 3			+33.6	+50.5	+2.7	+1.7
		3		May, 1921	308.5			1,735	9.7	41.7	6.06				2 and 3	3	11	−.3	−1.8	−.8	+1.3
Little Sioux River cut-off near Turin, Iowa.	22	1	2,680	1910	[1] 689.0			2,092	13.0	66.0	8.98										
		2		June, 1916	1,203.5	3.90	5.19	4,333	17.3	96.5	11.36	1.92	.075	0	1 and 3	7		+68.8	+82.0	+2.7	+43.7
		3		July, 1917	1,163.5			3,808	15.7	109.7	9.93				2 and 3	1	1	−3.3	−12.1	−1.6	+13.2

[1] Original cross sections at time of construction computed from dimensions of channels given in engineers' specifications. Not as much dependence can be placed upon these values as where measurements were made

Columns 16, 17, and 18 show the time that elapsed between the measurements as numbered in column 3. In columns 19 and 20 are given the per cent changes in the cross-sectional areas and the discharges during the periods between the measurements indicated in columns 17 and 18. Usually two values are given for each ditch, the first value indicating change that occurred between construction and the final measurements and the second indicating change between the first and the final measurements. Columns 21 and 22 give the changes in depth and top width, showing whether silting or erosion took place during the period of observation.

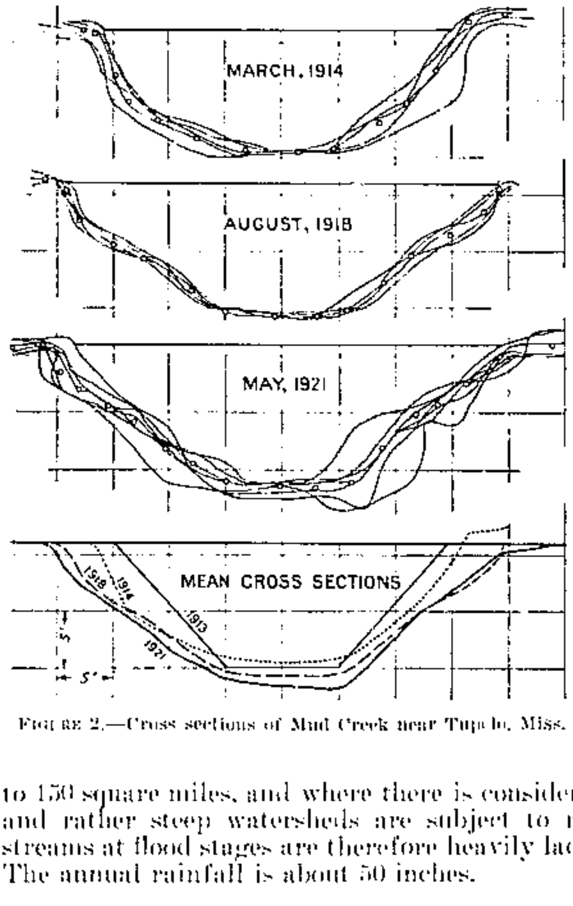


FIGURE 2.—Cross sections of Mud Creek near Tupelo, Miss.

DESCRIPTION OF CHANNELS

STREAMS IN LEE COUNTY, MISS.

Measurements of the following four channels were made in Lee County, Miss.: Mud Creek, Twenty Mile Creek, Chawappah Creek, and Coonewah Creek. Each of these channels was nearly 10 years old at the time of the last measurements and they therefore afford a good opportunity for the study of erosion and silting. The conditions in these channels are typical of those in the uplands of Mississippi and adjacent States where the watershed areas range from about 50 to 150 square miles, and where there is considerable fall. The rough and rather steep watersheds are subject to rapid erosion and the streams at flood stages are therefore heavily laden with silt and sand. The annual rainfall is about 50 inches.

MUD CREEK

Cross sections of this channel were measured along a course 1,194 feet in length just above the highway bridge about 1 mile east of Tupelo. The first measurements were made about one year after the channel was excavated, and the last measurements about eight years after the first. From Plate 1 it is apparent that the channel deteriorated greatly, having become choked with a growth of weeds,

Mud Creek, Miss.: A, February, 1913; B, May, 1921

Twenty Mile Creek, Miss.: A, February, 1913; B, December, 1920 sprouts, and willows. Although the stream has a comparatively good fall the rate of enlargement due to erosion was relatively slow (fig. 2) since the vegetation in the channel tended to decrease the velocity and protect the soil from erosion. The soil is an alluvial, sandy, waxlike clay.

TWENTY MILE CREEK

In this channel measurements were made over a course 324 feet long below the highway bridge about 1 mile east of Baldwyn. By referring to Table 1, it is seen that this channel increased rapidly, in both depth and width, for several years after construction; then sedimentation began and, while the widening continued, a considerable decrease in depth occurred as is shown in Figure 3. The large fall, freedom from vegetation (pl. 2), and susceptibility of the banks to caving were principally responsible for the rapid widening and erosion of this channel. The sandy nature of the soil rendered the banks particularly subject to caving, which was greatly accelerated by the weight of the spoil banks placed near the edge of the ditch. During the first few years after construction the water carried away most of the material that caved into the channel; but when caving

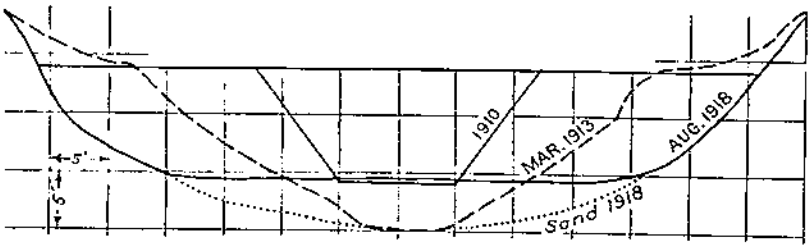
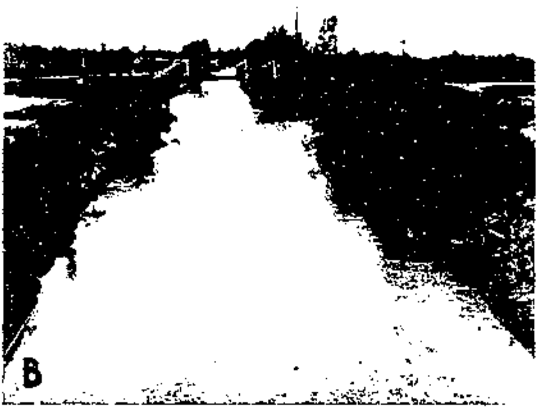


FIGURE 3.—Cross section of Twenty Mile Creek near Baldwyn, Miss.

of the spoil banks began, the material fell into the channel faster than it could be carried away by the water and much of it settled to the bottom. A part of the sediment was caused by silt and sand washed from the hills during floods, some of which was deposited in the channel when the floods subsided. Moreover, the velocity in the channel was decreased from year to year as the cross section grew larger. Figure 3 indicates the extent to which sediment was deposited. The soil is a waxy clay loam containing considerable sand which makes it particularly susceptible to erosion. Since construction, drainage conditions have continued to improve with the increasing discharge capacity of the channel.

CHAWAPPAH CREEK

Measurements of this channel were made along a course 320 feet in length between the highway and the railroad bridges one-half mile south of Shannon. The conditions governing erosion and silting on this channel were almost identical with those of Twenty Mile Creek, except that possibly the soil does not erode so easily. (Fig. 4.) The channel was practically free of vegetation in 1913, and except for a few small saplings contained little in 1921. (Pl. 3.) The soil varies from a sandy loam at the top to a waxy clay at the



Chawappah Creek, Miss.: A, February, 1913; B, May, 1921 bottom. The discharge capacity increased, but not as much as in the case of Twenty Mile Creek, since the hydraulic radius decreased after 1913, while that of Twenty Mile Creek showed a small increase. The increase in discharge capacity between 1913 and 1921 was not sufficient to cause much improvement in drainage conditions, while the increase prior to that time effected a very decided improvement.

COONEWAH CREEK

Cross sections of this channel were measured along a course of 150 feet between the highway and the railroad bridge about

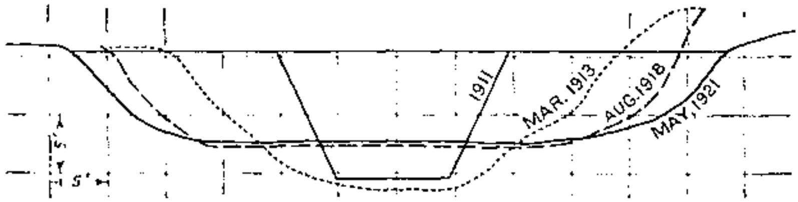


FIGURE 4.—Cross section of Chawappah Creek near Shannon, Miss.

three-fourths of a mile north of Shannon. During the first few years after construction this channel was practically free of vegetation, and its enlargement due to erosion and caving of the banks was very rapid. (Pl. 4 and fig. 5.) A growth of heavy grass then appeared in the channel; erosion was checked and silting took place, giving the condition of the channel as at the last measurements. Later, the channel was cleaned out and somewhat enlarged by the use of dynamite. The view in Plate 4, B, was taken after this work was done. The soil is a sandy clay loam. The increase in discharge capacity since construction resulted in improved drainage conditions.

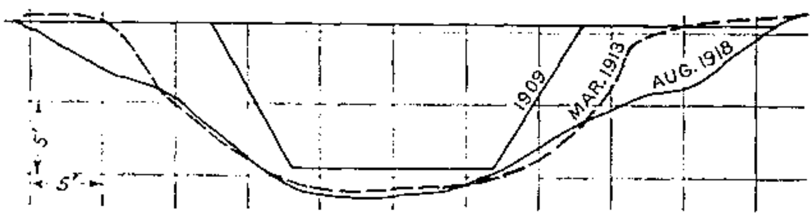
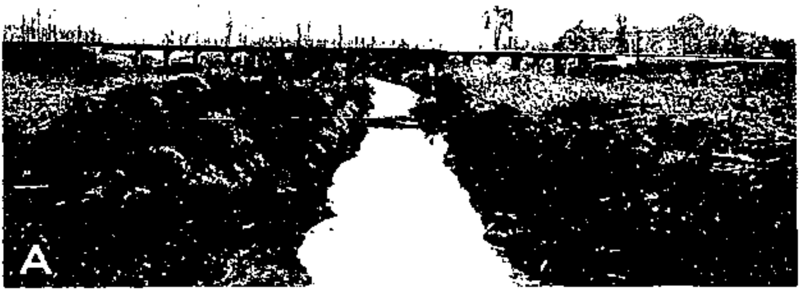


FIGURE 5.—Cross section of Coonewah Creek, near Shannon, Miss.

STREAMS IN BOLIVAR COUNTY, MISS.

Five streams in Bolivar County measured were Bogue Phalia, Bogue Hasty, Pecan Bayou, Wes. Bogue Hasty, and East Bogue Hasty. The watershed areas vary in size from 13 square miles for Pecan Bayou to 323 square miles for Bogue Phalia. The watersheds of these channels are practically flat, the streams being in a part of the bottom lands of the Mississippi River commonly known as the Delta.

Erosion and silting conditions in Bolivar County are quite different from those in Lee County. Practically no erosion occurs on the watersheds in Bolivar County, so that what little silt is found in the



Coonewah Creek, Miss.: A, February, 1913; B, May, 1921 channels is eroded from the banks and bed. Excepting Bogue Phalia, no appreciable erosion occurred in these channels, the hydraulic radius and fall being too small to produce sufficient velocity to cause erosion. Although Bogue Phalia has only a slight fall, it has a large hydraulic radius to which is due the high velocity that results in considerable erosion. Conditions governing silting and erosion in Bolivar County are typical of those prevailing on the bottom lands of most large rivers where the watersheds of the tributary streams are confined to the bottom lands. The annual rainfall is about 50 inches.

BOGUE PHALIA

Measurements of this channel were made on a course 1,083 feet long located about one-half mile above the bridge of the Yazoo & Mississippi Valley Railroad about 2 miles from Helm. Up to the time the first measurements were made (January, 1915) the channel had increased in depth, width, and hydraulic radius. (Fig. 6.) After that a slight increase in the depth and a considerable increase in the width occurred, but the hydraulic radius did not change greatly. The bottom was covered with about one-half foot of sand, and considerable vegetation, such as willow and cottonwood saplings, was found in the channel at the time the measurements were

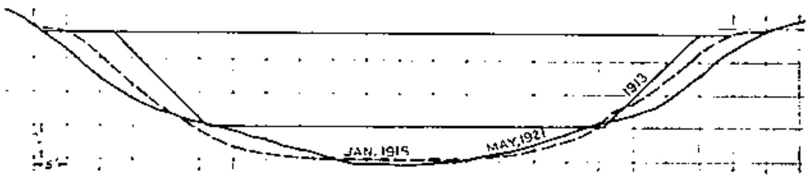


FIGURE 6.—Cross section of Bogue Phalia, near Helm, Miss.

made in 1921. (Pl. 5, B.) A view of the same course of channel taken during April, 1915, is shown in Plate 5, A. At that time the channel contained very little vegetation, and the banks were sloughing off very rapidly. This action was caused by the sandy nature of the soil, the great depth of channel, and the effect of frost. Some undermining of the banks resulted from the washing away of sandy layers in the soil. When the widening of the channel reached the spoil banks the caving action was greatly increased by the weight of the latter. When the slight fall of the channel is considered, the velocity appears to be rather high, a condition due to the large hydraulic radius and the low frictional resistance to flow. The upper soil is a clay loam, below which is a sandy loam.

BOGUE HASTY

A course of 1,039 feet just above the highway bridge about 3 miles west of Shaw was selected. Table 1 shows that the velocity in this channel was low, being only half that in the channel of Bogue Phalia. The slight increase in cross-sectional area was chiefly due to sloughing of the banks. (Fig. 7.) When the measurements were made in 1915 the upper part of the channel was covered with weeds and small tree sprouts. This growth increased from year to year

Bogue Phalia, Miss.: A, April, 1915; B, May, 1921 until by 1920, when the growth was removed, the channel had become choked with small willow and cottonwood trees. Views of the channel are shown in Plate 6. The upper soil of the channel is a dark, silty loam, and the lower a dark-yellow clay, which is sticky when wet and which cracks and crumbles when dry.

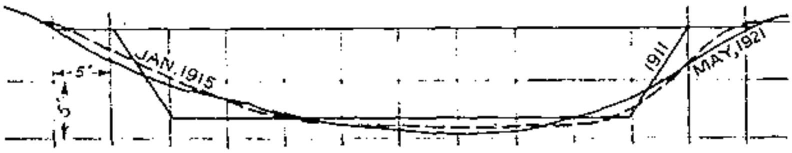


FIGURE 7.—Cross section of Bogue Hasty, near Shaw, Miss.

PECAN BAYOU

Cross-sectional measurements of this channel were made along a course of [illegible]35 feet, about 600 feet above the highway bridge 5 miles south of Skene and about 3 miles northwest of Shaw. This channel has a very low velocity and little fall. The cross-sectional area

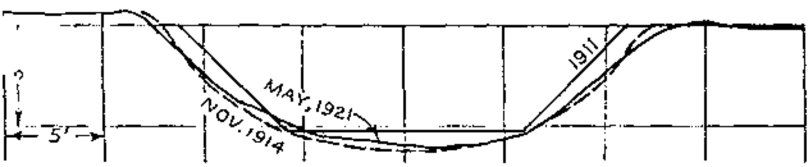


FIGURE 8.—Cross section of Pecan Bayou, near Shaw, Miss.

decreased slightly between 1914 and 1921 due to silting caused largely by vegetation which grew up in the channel. (Fig. 8.) Had it not been for this growth, the channel would no doubt have undergone little change. (Pl. 7.) The soil is a dark waxy clay.

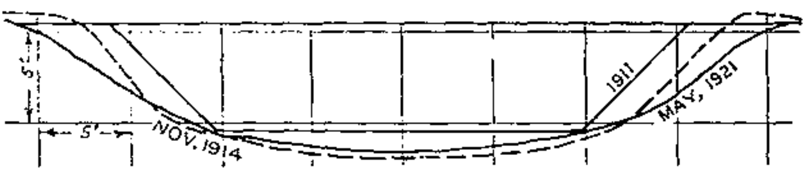


FIGURE 9.—Cross section of West Bogue Hasty, near Shaw, Miss.

WEST BOGUE HASTY

Measurements of this channel were made along a course of 757 feet above the highway bridge about 1 mile east of Litton and 6 miles northwest of Shaw. This channel has a very low velocity; a slight increase in the cross section of the channel resulted from the tendency of the banks to slough when alternate freezing and thawing occurred. As shown in Figure 9, the channel decreased in depth and gained in width.

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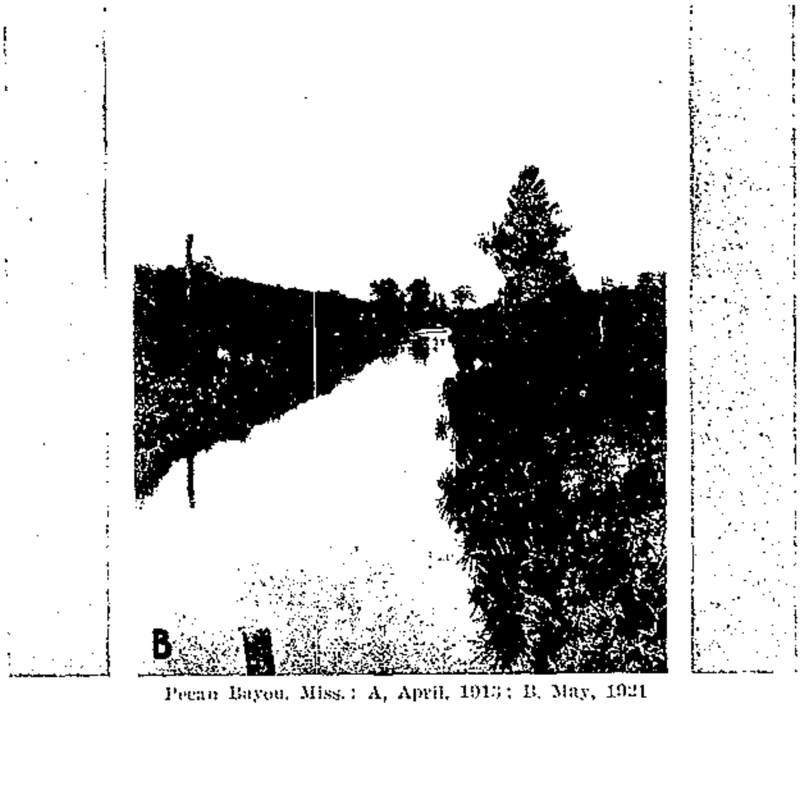
Bogue Hasty, Miss.: A, April, 1915; B, May, 1921



Pecan Bayou, Miss.: A, April, 1913; B, May, 1921

West Bogue Hasty, Miss.: A, April, 1915; B, May, 1921

Views of the channel are presented in Plate 8. In 1915 a few weeds were found on the slopes, and between that time and 1920, when the channel was cleared, a thicket of brush, sprouts, and small saplings grew up. Plate 8, B, shows the banks lined with a thick, short growth of vegetation which sprang up after the channel was cleared in 1920. The soil is similar to that found in the channel of Bogue Hasty.

EAST BOGUE HASTY

For measurements of this channel a course 502 feet long just above the highway bridge about 2 miles east of Litton and 5 miles northwest of Shaw was selected. Between November, 1914, and May, 1921, this channel decreased in cross-sectional area on account of silting. (Fig. 10.) No doubt this silting was caused by the thick growth of sprouts and saplings that sprang up in the channel between 1915 and 1920, when the channel was cleared. Views of the channel are shown in Plate 9. The soil is a dark clay which cracks and crumbles when dry.

STREAMS IN WESTERN TENNESSEE

Measurements of seven channels were made in western Tennessee: South Forked Deer River at Roberts, Jackson, and Henderson;

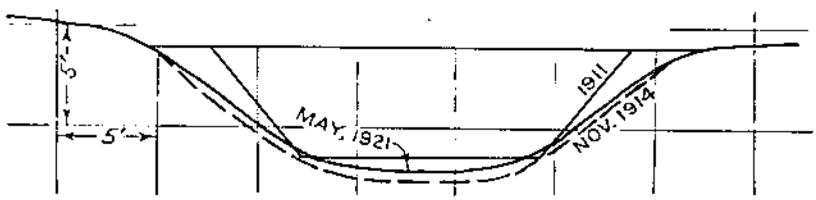


FIGURE 10. Cross section of East Bogue Hasty near Shaw, Miss.

North Forked Deer River; Huggins Creek; Sugar Creek; and Cypress Creek. The watersheds vary in size from 6 square miles for Cypress Creek to 704 square miles for the South Forked Deer River at Roberts. Conditions as to erosion and silting in these channels are similar to those found in the channels in Lee County, Miss. However, they cover a much wider range with respect to areas of watersheds and size of channels. The topography of these watersheds ranges from gently rolling to very rough and hilly, and considerable surface erosion occurs. The annual rainfall is about 50 inches.

SOUTH FORKED DEER RIVER, NEAR ROBERTS, TENN.

Cross sections of this channel were measured along a course 1,412 feet in length just above the highway bridge about 1 mile south of Roberts. Since construction the channel has been quite free from irregularities in the sides and bed and practically free from vegetation. Although it has a comparatively slight fall, its high velocity, which has caused a rapid rate of erosion, is due to its large hydraulic radius and low frictional resistance to flow as indicated by the low value of n obtained. The hydraulic radius and the cross-sectional area increased materially between 1915 and 1921. (Fig. 11.) This

East Bogue Hasty, Miss.: A, April, 1915; B, May, 1921

A

South Forked Deer River near Roberts, Tenn.: A, July, 1917; B, May, 1921 increase came from a widening of the channel due both to the caving of the banks after the recession of floods and to erosion of the soil. The soil is an alluvial silt loam. Views of the channel are shown in Plate 10.

SOUTH FORKED DEER RIVER NEAR JACKSON, TENN.

The channel at this point was cross-sectioned along a course of 952 feet above the Bolivar Levee road bridge about one half mile from Jackson. Although the channel at this point has a much greater fall than at Roberts, yet the velocity is slightly less since

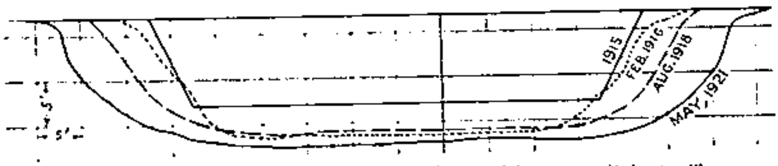


FIGURE 11.—Cross section of South Forked Deer River near Roberts, Tenn.

it has a smaller hydraulic radius and a greater resistance to flow as indicated by the values of n obtained for the respective channels. (Table 2.) A fair comparison of the rates of erosion of the two channels can not be made since only a short time elapsed between the two sets of cross-sectional measurements at Jackson. The soil is a firm, waxy clay and does not seem to erode or cave easily. Between January, 1917, and August, 1918, the channel increased in depth but not in width. (Fig. 12.) There was practically no vegetation in the channel as may be seen from the views in Plate 11.

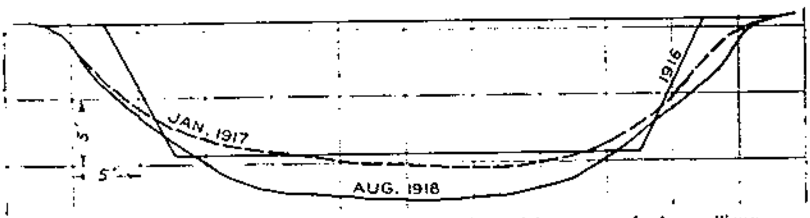


FIGURE 12.—Cross section of South Forked Deer River near Jackson, Tenn.

SOUTH FORKED DEER RIVER NEAR HENDERSON, TENN.

Cross sections were measured along a course of 624 feet above the steel highway bridge about 2 miles east of Henderson. This channel was not enlarging as fast here as at Jackson and Roberts since it had a smaller hydraulic radius and a lower velocity. As may be seen in the views in Plate 12, there was not much vegetation in the channel and the banks were irregular and caving. Silting amounting to over one-half foot in depth occurred between April, 1916, and May, 1921, when the channel was in good condition and had increased considerably in discharge capacity since construction. (Fig. 13.) The soil is a silty loam.

South Forked Deer River near Jackson, Tenn.: A, June, 1917; B, May, 1924

NORTH FORKED DEER RIVER

This channel was measured along a course 700 feet in length above the Huntingdon Levee road about one-half mile from Trenton. The high velocity of flow was partly caused by the low frictional resistance, there being very little vegetation in the channel as may be seen from the views in Plate 13. The erosive action of the water on the sides and bed of the channel and the caving and sloughing of the banks caused an enlargement in both depth and width of the channel. An idea as to the progressive erosion of the channel can be obtained from Figure 14. The soil varies from an alluvial silty loam at the top to a heavy silty clay at the bottom of the chan-

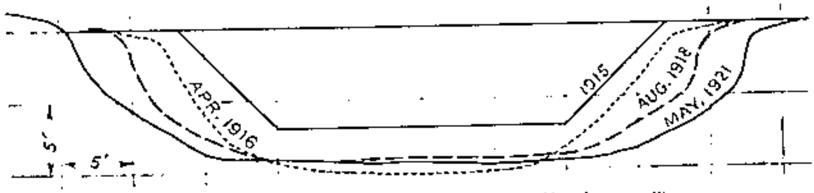


FIGURE 13. South Forked Deer River near Henderson, Tenn.

nel and is quite susceptible to erosion. The increase in discharge capacity of this channel since construction has greatly improved drainage conditions.

HUGGINS CREEK

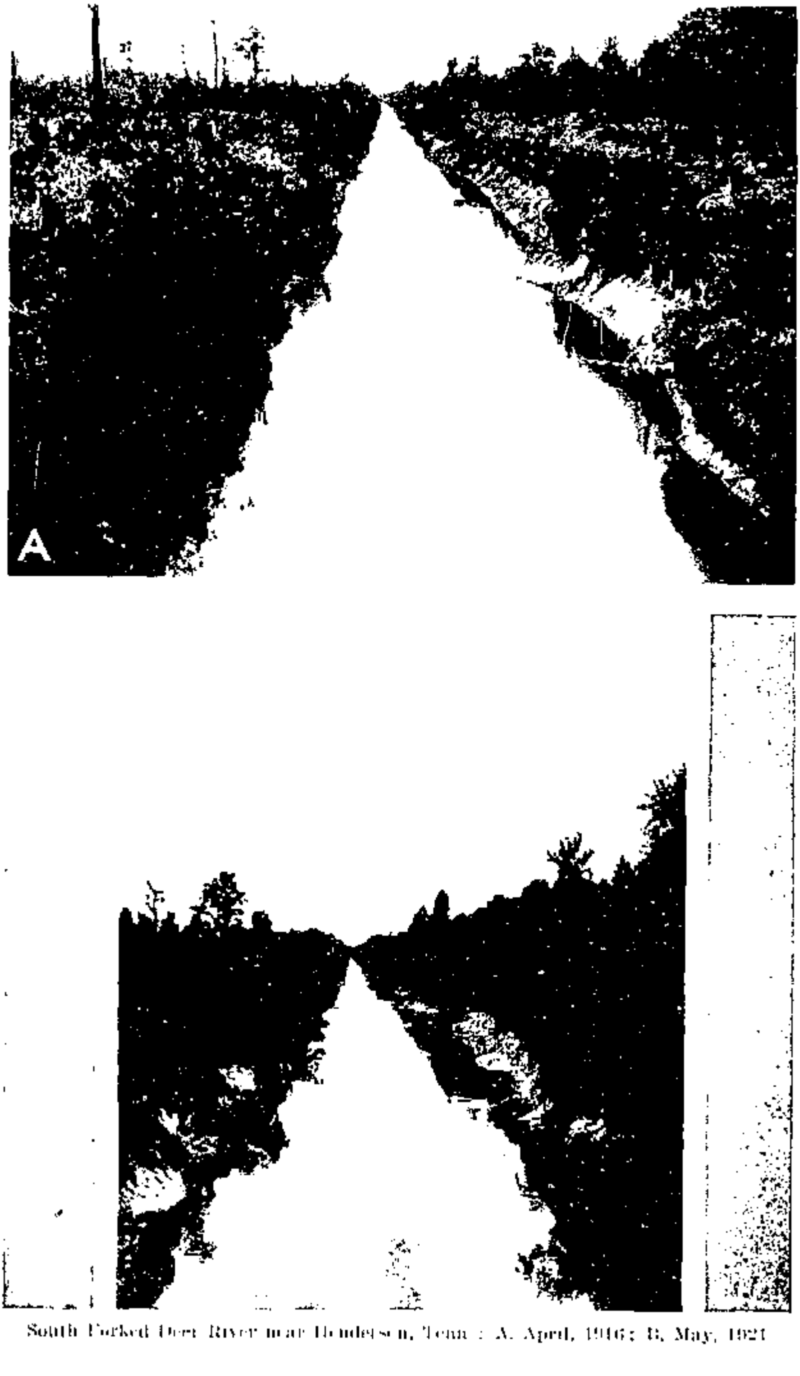
Cross sections of this channel were measured along a course of 914 feet above the highway bridge located about 100 yards east of the Mobile & Ohio Railroad near Finger. This channel is very irregular, and the side slopes are covered with vegetation, both factors contributing to the low velocity. (Pl. 14.) Moreover, the channel is small and has a small hydraulic radius. The vegetation

FIGURE 14. Cross section of North Forked Deer River, near Trenton, Tenn.

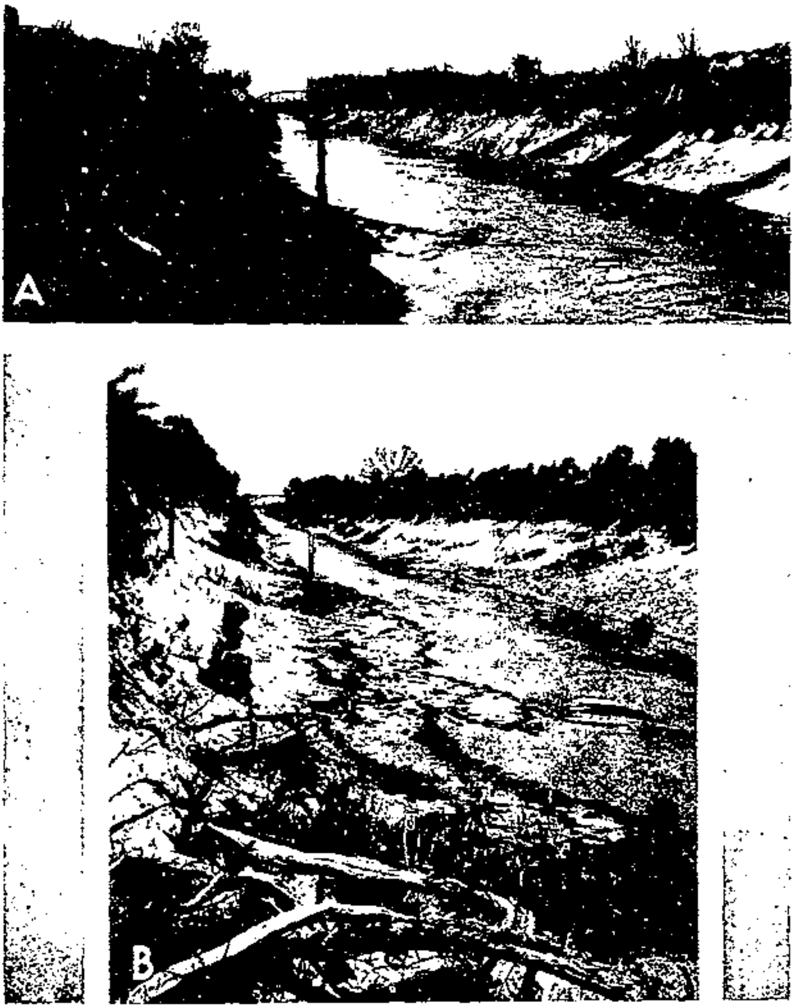
to a considerable extent prevented erosion, and the velocity of the water was insufficient to pick up all the material that sloughed off the banks of the channel. This and the Sugar Creek Channel are examples of a very slow rate in the enlargement of a channel even where the slope is comparatively great. The soil is principally a heavy silty loam. See Figure 15 for cross sections.

SUGAR CREEK

Measurements of cross sections of this channel were made along a course of 669 feet, half of the course being straight and half a smooth, easy curve. Both the sides and bottom of the channel were



South Forked Deer River near Henderson, Tenn.: A, April, 1916; B, May, 1921



North Forked Deer River, Tenn.: A, April, 1916; B, May, 1921

Huggins Creek, Tenn.: A, July, 1917; B, May, 1921

Sugar Creek, Tenn.: A, June, 1917; B, May, 1921 irregular. (Pl. 15.) As shown in Plate 15, A, there was practically no vegetation in the channel, whereas in May, 1921, some vegetation was present, as indicated by Plate 15, B. Although the channel had more fall than any of the channels heretofore mentioned in this group, yet a much lower velocity prevailed because the frictional

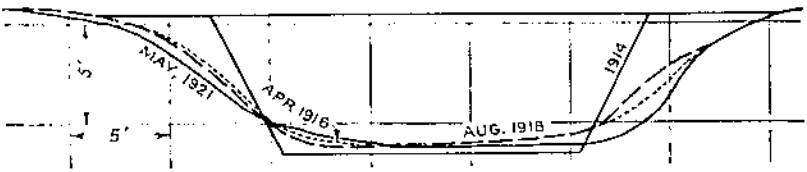


FIGURE 15.—Cross section of Huggins Creek dredged channel, near Finger, Tenn.

resistance to flow was large and the hydraulic radius small. Attention is particularly called to this fact since an opinion commonly prevails that the greatest erosion takes place in a channel with the greatest fall regardless of the other factors. The soil in the channel is a light-yellow clay, very tenacious and much less easily eroded than the soil in the channel of South Forked Deer River. Cross

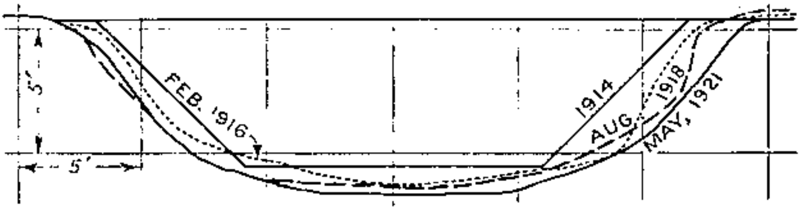


FIGURE 16.—Cross section of Sugar Creek, near Henderson, Tenn.

sections in Figure 16 show that the rate of erosion in this channel was comparatively slow during the period of observation.

CYPRESS CREEK

Cross sections of this channel were measured along a course 308 feet long above the highway bridge at Bethel Springs. This channel increased in width on account of erosion of the banks, but not much

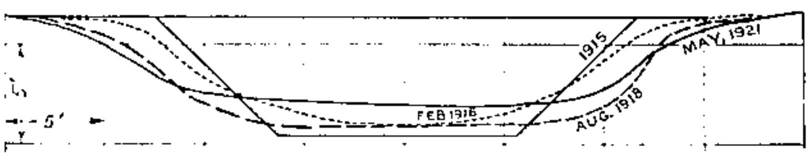
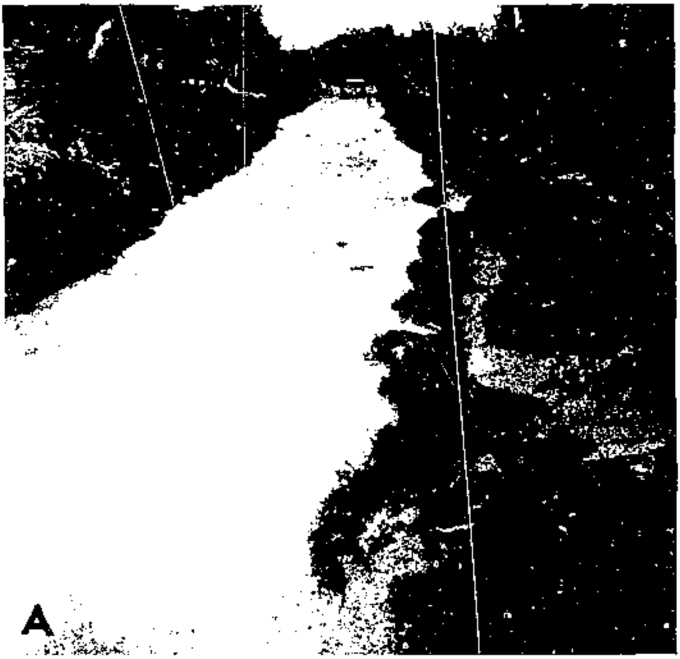


FIGURE 17.—Cross section of Cypress Creek, near Bethel Springs, Tenn.

change occurred in sectional area because the channel decreased in depth as a result of the deposition of silt and sand. (Fig. 17.) This may seem unusual since Cypress Creek has a much greater fall than any of the other measured channels in Tennessee. However, its hydraulic radius is very small, and the side slopes are protected from erosion by vegetation. (Pl. 16.) The silt and sand in the bottom of



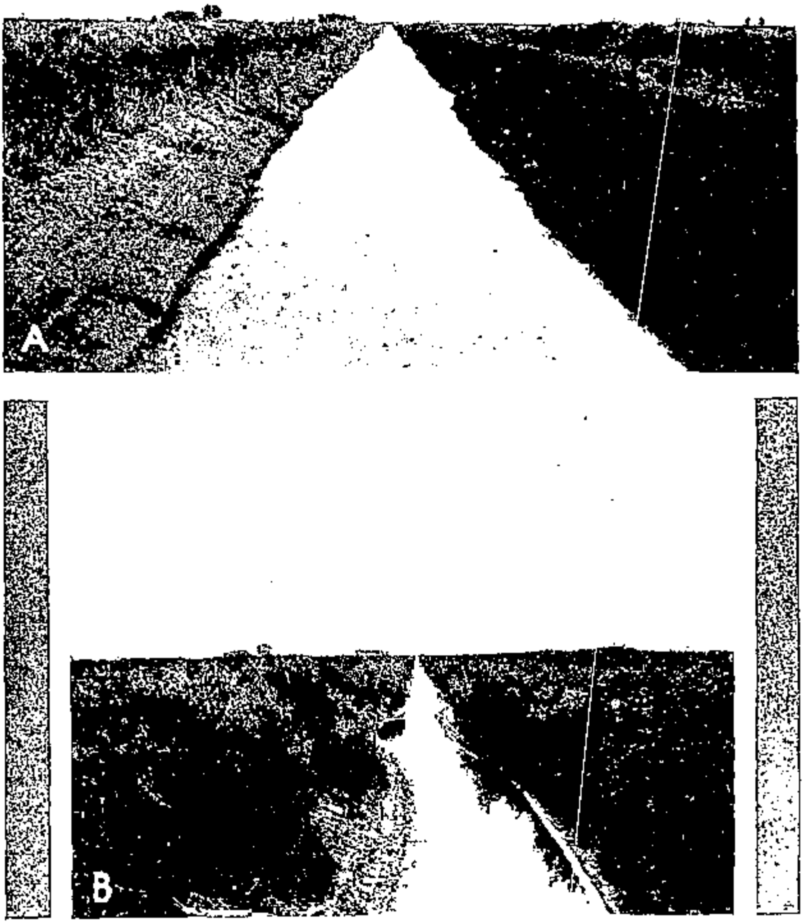
Cypress Creek, Tenn.: A, August, 1917; B, May, 1921 the channel come principally from the watershed where erosion is very active. Although the channel has a fairly high velocity, the water is overloaded with soil washed from the hill slopes and is forced to drop part of it in the channel. The deposition of silt is due also to the rapid decrease in discharge and consequent decrease in velocity following floods. Because of the slight depth of the channel very little caving of the banks has occurred.

STREAMS IN WESTERN IOWA

Measurements of six channels in western Iowa were made: Allen Creek, Willow Creek, Boyer River at Missouri Valley and at Dunlap, Pigeon Creek, and Little Sioux River cut-off. The watershed areas of these streams vary from 59 square miles for Allen Creek to 2,680 square miles for the Little Sioux River cut-off. The watersheds lie principally in the uplands, which vary from undulating to rolling and rough, and the ground surface is subject to considerable erosion; during floods the streams are therefore heavily charged with the eroded soil. During one of the largest floods a bucket of water taken from a stream contained about one-fourth silt by volume. The streams, particularly those in the vicinity of Missouri Valley and Crescent, are affected by backwater from the Missouri River. During periods of backwater the velocity is greatly reduced and silting takes place. However, when a high stage occurs in a channel during a low stage of the Missouri River, the water has a velocity sufficient to carry away a large part of the silt previously deposited. The annual rainfall is about 30 inches.

ALLEN CREEK

Cross sections of this channel were made along a course 794 feet long below the first highway bridge north of the Chicago & North Western Railway about 1 mile west of Missouri Valley. This channel had been redredged shortly before the first measurements were made in June, 1917. In Plate 17 are shown views of the channel. In the first view it is seen that the channel is uniform in cross section, that vegetation was springing up over the flat side slopes, and that the slopes were covered with a coating of silt of a slick nature. The soil is a dark, silty loam. The growth of vegetation continued to increase until four years later the channel was in very bad condition, as shown in the second view. The absence of caving banks was no doubt because of the flat side slopes, and the lack of erosion, which usually occurs with such a high velocity, probably was attributable to the presence of vegetation. Silting occurs at times of reduced velocity when the stream is affected by backwater from Missouri River, and the rate of silting is increased by the vegetation in the channel. No doubt large quantities of silt were carried away during periods of high velocity, but this action was not sufficient to keep pace with the rapid silting during periods of backwater. The decrease in cross-sectional area (fig. 18) of this channel only being considered, and the effect of vegetation being disregarded, the discharge capacity decreased materially between 1917 and 1921.



Allen Creek, Iowa: A, June, 1917; B, May, 1921

WILLOW CREEK

Measurements of this channel were made along a course of 1,004 feet below the Chicago & North Western Railway bridge at Missouri Valley. This channel was redredged in 1917. In Plate 18 are shown views of the channel, the first taken shortly after the channel had been redredged, and the other about four years later. Both silting and erosion have occurred in the channel as may be seen from the views and from the cross sections in Figure 19. In June, 1917, the channel was practically free of vegetation, but four years later considerable vegetation was present in the upper part of the channel, although much less than was found in the channel of Allen Creek.

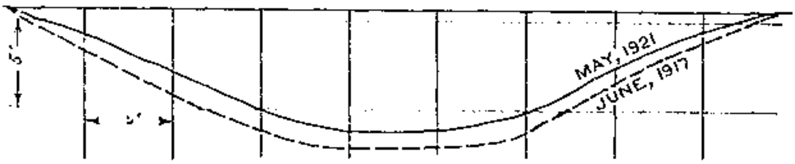


FIGURE 18. Cross section of Allen Creek near Missouri Valley, Iowa

It is believed that this accounts for the fact that there was erosion in this channel whereas there was none in Allen Creek, and that less silting took place even though the fall and velocity were less than in the case of Allen Creek. The silting that occurred was on account of the reduced velocity caused by backwater from the Missouri River. The soil is a heavy, dark, silty loam similar to that found in Allen Creek. Were it not for vegetation in the channel, the discharge capacity would have been somewhat larger in 1921 than in 1917 when the first cross-sectional measurements were made.

It appears that vegetation grew much more rapidly in Allen Creek probably because the drainage area and therefore the low-water flow was less than in Willow Creek. The effect of vegetation in this chan-

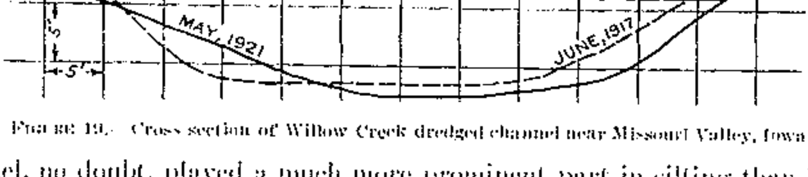


FIGURE 19. Cross section of Willow Creek dredged channel near Missouri Valley, Iowa

nel, no doubt, played a much more prominent part in silting than in the channel of Willow Creek since, judging from conditions shown in Plate 17, B, the value of the roughness coefficient must have been high and the velocity correspondingly low.

BOYER RIVER NEAR MISSOURI VALLEY, IOWA

Cross-sectional measurements of this channel were made above the Lincoln Highway bridge about 1 mile from Missouri Valley, along a course 868 feet in length. Although this channel has but

Willow Creek, Iowa: A, June, 1917; B, May, 1924 little fall, it has a high velocity due to its large hydraulic radius and very low resistance to flow, the value of *n* obtained for this channel at bank-full stage being 0.0151. Enlargement of this channel from erosion and caving of the banks has been very rapid. (Fig. 20.) This caving has been accelerated considerably by the weight of the spoil banks, most of which have caved into the channel. At the time of the measurements in 1921 about 2 feet of silt lay in the bottom of the channel. Silting occurs at one time and erosion or the washing out of the silt at another, depending upon whether or not the slope and velocity are reduced by backwater from the Missouri River. Since this channel drains about 900 square miles, there is always an appreciable low-water flow which prevents the growth

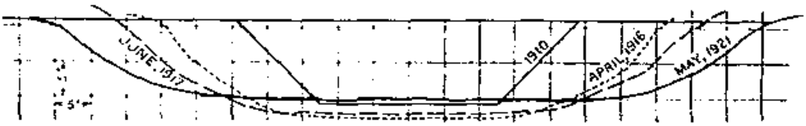


FIGURE 20. Cross section of Boyer River near Missouri Valley, Iowa

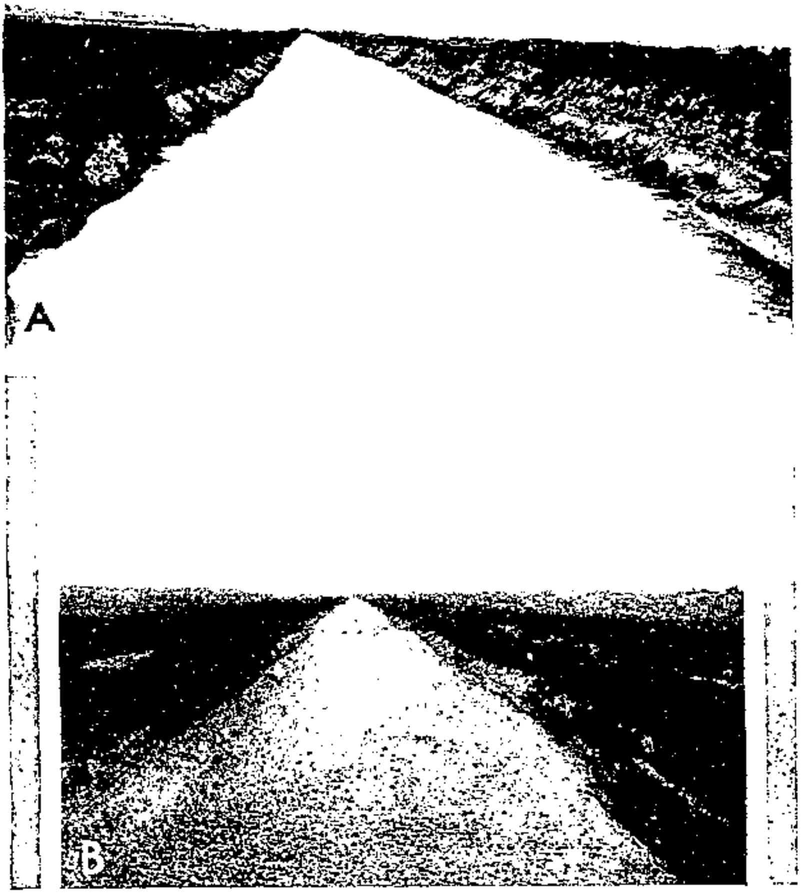
of vegetation in the bottom. There was practically no vegetation on the side slopes in 1921. The soil is a dark, silty loam underlaid by a hard, yellow clay. The considerable increase in the discharge capacity of this channel that accompanied the large increase in cross-sectional area resulted in a decided improvement in drainage conditions over the adjoining bottom lands. Plate 19 shows views of the channel.

BOYER RIVER NEAR DUNLAP, IOWA

This channel was measured on a course 904 feet long above the highway bridge about one-half mile southwest of Dunlap. It has a

FIGURE 21. Cross section of Boyer River near Dunlap, Iowa

comparatively great fall and large hydraulic radius, both factors being responsible for its rapid enlargement from erosion. (Fig. 21.) About June, 1917, silting started and in May, 1921, there was about $1\frac{1}{2}$ feet of silt in the bottom of the channel. The rapid widening was caused chiefly by caving of the banks which, in turn, was caused by deepening from erosion and by the weight of the spoil banks. By 1921 the original spoil banks were practically gone. In June, 1917, there was no vegetation in the channel—a condition no doubt due to the rapid caving of the banks and the fairly large low-water flow. In May, 1921, considerable vegetation had started on the upper side slopes of the channel. (Pl. 20.) Measurements for the value of *n* were not made for bank-full stages, but it is believed that a very low value would have been obtained before the growth of



Boyer River near Missouri Valley, Iowa: A, June, 1917; B, May, 1921 vegetation in this channel. The percentage of increase in cross-sectional area was greater than for any other channel measured. The discharge capacity increased to such an extent that by 1921 the adjoining lands were practically free from flood hazard. The soil in the bottom of the channel is a very hard, whitish clay, and in the upper part of the side slopes it is a silty loam. The Boyer River at Dunlap is not affected by backwater from the Missouri River.

PIGEON CREEK

Measurements of this channel were made along a course of 858 feet below the highway bridge about one-half mile above the Chicago

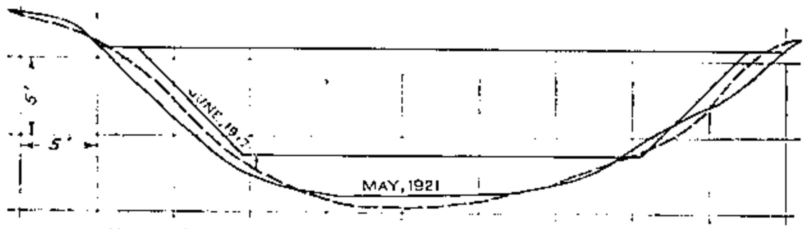


FIGURE 22. Cross section of Pigeon Creek near Crescent, Iowa

& North Western Railway near Crescent. The cross-sectional area did not change materially between 1917 and 1921. (Table 3 and fig. 22.)

A slight increase in width and some silting in the channel have occurred. The channel is not so deep as that of the Boyer River at Dunlap and at Missouri Valley, and the spoil banks were set farther from the edge of the ditch so that there has been very little caving as compared with that along the Boyer River. Silting occurs at times, due to backwater caused by high stages in the Missouri River. The condition of the channel is shown by the views in Plate 21.

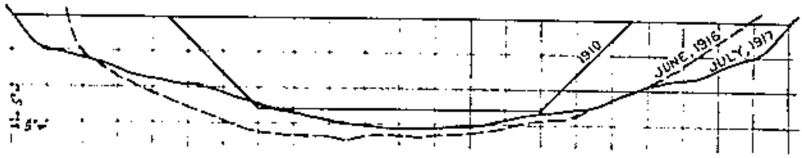
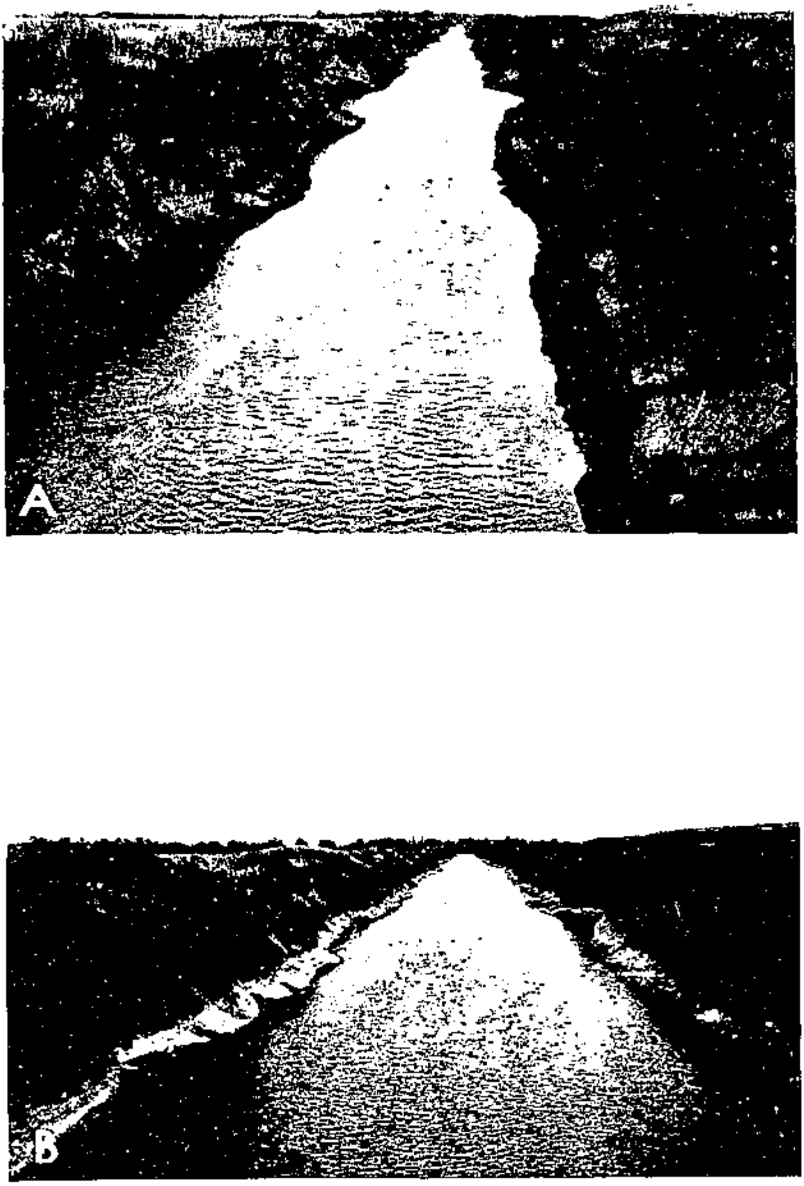


FIGURE 23. Cross section of Little Sioux River near Turin, Iowa

From these it is seen that vegetation in the channel increased between 1917 and 1921. The soil is a heavy, dark, silty loam.

LITTLE SIOUX RIVER CUT-OFF

This channel was measured along a course of 1,212 feet above the highway bridge on the Onawa-Turin road about one-half mile from Turin. It enlarged very rapidly until about June, 1916, when the right bank began to cave and carried into the channel trees and a part of the roadway that was built on the spoil bank. The comparatively high velocity for the moderate slope is due to the large hydraulic radius. In Figure 23 is shown a partial filling of the



Boyer River near Dunlap, Iowa: A, June, 1917; B, May, 1921 channel which occurred after June, 1916. The views in Plate 22 show the condition of the channel as to the presence of vegetation. The spoil banks were placed close to the edge of the channel and thus accelerated the caving of the banks. The material that caved into the channel, being held together by roots and vegetation, was removed very slowly by the current. The soil in the upper part of the

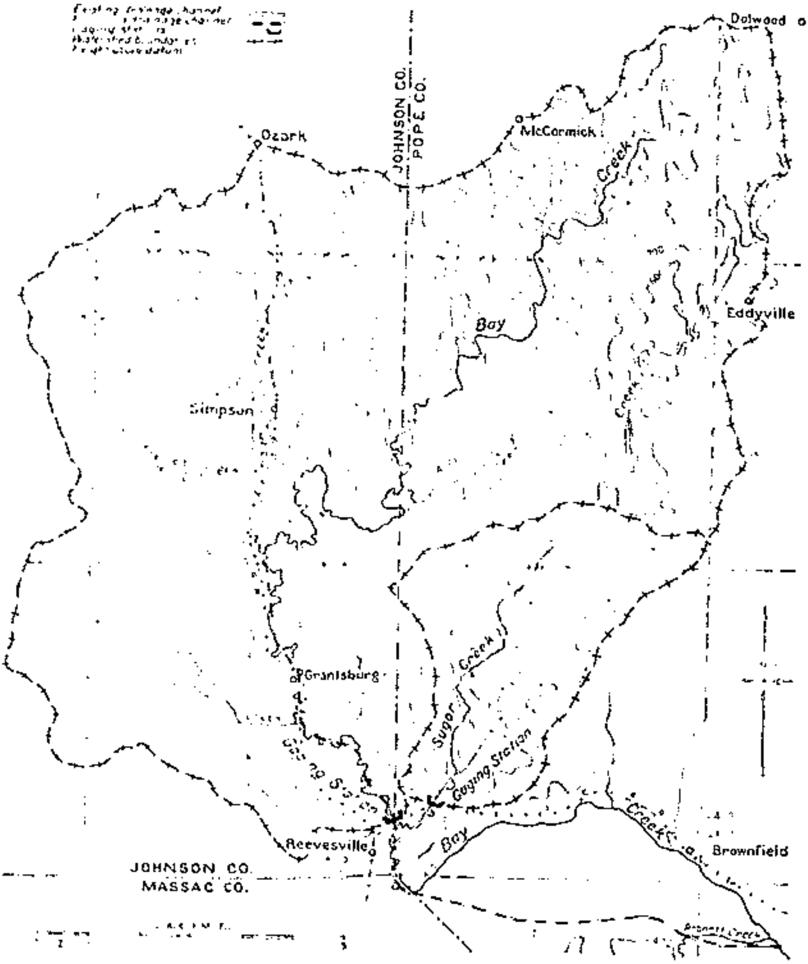
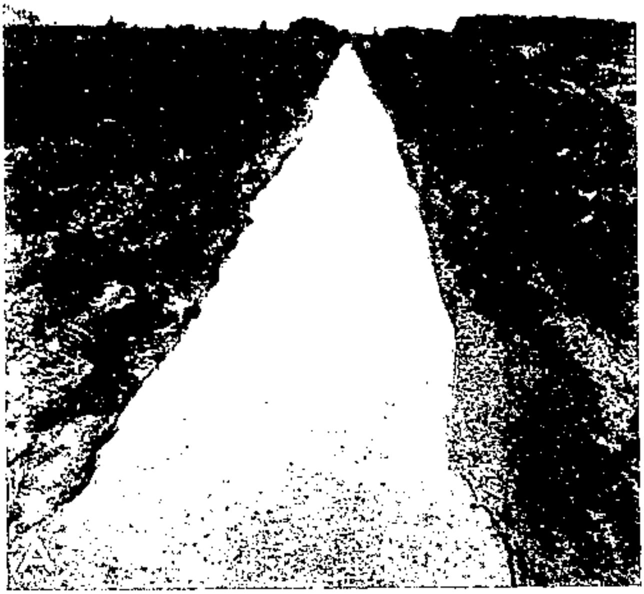


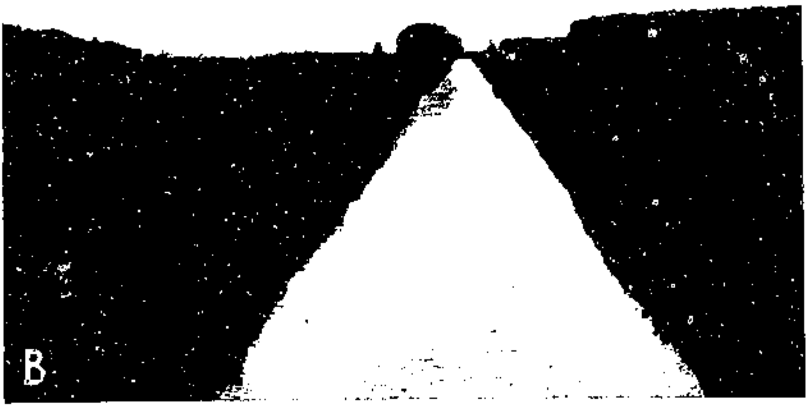
FIGURE 21. Map of the watershed of Bay Creek, Ill.

channel is a dark, silty loam and in the lower part a heavy, hard, light-colored clay.

APPLICATION OF RESULTS

To show the practical application of the results presented in this bulletin, these results have been applied to the design of a dredged channel on the Bay Creek watershed in southern Illinois. Figure 24 is a map of the Bay Creek watershed. The part of the channel





Pigeon Creek Iowa: A, June, 1917; B, May, 1921

Little Sioux River Cut-off, Iowa: A, June, 1916; B, June, 1917

TABLE 4.—*Comparison of factors influencing erosion*

Stream	Watershed: Area	Watershed: Relief	Soil along channel	Mean annual rainfall	Dimensions of channel: Reference No. of measurement	Dimensions of channel: Date	Dimensions of channel: Mean maximum depth	Dimensions of channel: Mean top width	Dimensions of channel: Mean hydraulic radius	Mean cross-sectional area	Value of Kutter's n	Fall of channel	Mean normal velocity	Discharge	Time elapsed between measurements: Reference No.	Time elapsed between measurements: Years	Time elapsed between measurements: Months	Per cent change: Area	Per cent change: Discharge
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Sq. mi.			*In.*			*Feet*	*Feet*	*Feet*	*Sq. ft.*		*Ft. per mi.*	*Ft. per sec.*	*Cu. ft. per sec.*					
North Forked Deer River near Trenton, Tenn.	93	Varies from gently rolling to very rough and hilly; erosion very active.	Varies from alluvial silty loam at top to heavy silty clay at bottom; easily eroded and subject to caving.	50	1 2 3 4	May, 1915 Apr., 1916 Jan., 1917 Aug., 1918	8.0 11.2 11.0 11.1	36.0 42.0 55.0 57.2	5.3 6.6 6.6 7.0	221.0 331.0 402.4 450.7	0.0265	2.77	3.91 1.57 4.76	884.0 1,512.0 1,848.0 2,141.0	1 and 4 2 and 4	3 2	3 4	+101.2 +36.1	+142.9 +11.8
Bay Creek near Reevesville, Ill.	146	Rough and hilly; very little level land except in bottoms; many gullies and much badly eroded land.	Fine sandy loam, subject to caving and easily eroded.	45	[3] 1 [4] 2		10.0 12.0	55.0 79.0	7.1 9.0	150.0 801.0	.0300 .0300	2.61 2.61	4.18 4.90	1,884.0 3,910.0	1 and 2			+78.7	+109.5

[3] Channel recommended to be constructed.

[4] Channel required.

considered extends upstream from the mouth of Sugar Creek near Reevesville, to the mouth of Cedar Creek. It is not affected by backwater to an appreciable extent.

Data pertinent to the possibilities of erosion and silting in the Bay Creek Channel are given in Table 4, and for comparison corresponding actual figures are shown for the North Forked Deer River near Trenton, Tenn.

The watershed area of the North Forked Deer River is 93 square miles as compared with 116 square miles for the part of Bay Creek under consideration. Other factors being the same the rate of erosion and silting would be greater for the larger watershed. (See p. 10, Volume of run-off water.)

In column 3 of Table 4 the topography of each watershed is described briefly. It would appear that erosion is even more active on the Bay Creek than on the North Forked Deer River watershed. As a result a greater charge of silt would be expected in the run-off water from the former than from the latter. (See p. 9, Silt charge in streams.)

From column 4 it is seen that the soils along both channels are subject to caving and are easily eroded, from which it appears that, other factors being the same, erosion or silting would proceed at about the same rate in both channels. The side slopes for the Bay Creek Channel would stand at about 1 on $1\frac{1}{2}$. (See p. 6, Caving and sloughing banks.)

The annual rainfall on the Bay Creek watershed is about 45 inches and on the North Forked Deer River watershed, 50 inches. Hence it would be expected that the rate of erosion and silting would be somewhat greater for the latter than for the former stream. (See p. 10, Volume of run-off water.)

The fall along the two channels is about the same. The fall, the hydraulic radius and the condition of the channel as regards resistance to flow determine the velocity in a channel. (See p. 4, Velocity due to three factors.) The resistance to flow is measured by the value of n in Kutter's formula. The value of n for the North Forked Deer River Channel was found by measurement to be 0.0265 and was for the purpose of design assumed to be 0.030 for the Bay Creek Channel. The hydraulic radius varied from 5.3 feet to 7 feet for the North Forked Deer River Channel and was found to be 9 feet for the required size of channel for Bay Creek. The velocity of flow was determined for each of the two channels and was found to range from 3.94 feet per second at the beginning to 4.76 feet per second at the close of the investigations on the North Forked Deer River Channel, and to be 4.90 feet per second for the required size of the Bay Creek Channel. In the North Forked Deer River Channel the velocity was at all times greater than 3 feet per second, which is sufficient to cause erosion. (See p. 2, Relation of velocity to erosion and silting.) Since the velocity for the required size of channel for Bay Creek is slightly greater than that in the North Forked Deer River Channel at the end of the investigations, it may be inferred that erosion would occur in the proposed channel of Bay Creek.

The mean cross-sectional area of the North Forked Deer River Channel increased from 224.0 square feet to 450.7 square feet, and the discharge from 883 cubic feet per second to 2,144 cubic feet per second. This is an increase in cross-sectional area of 101.2 per cent and in discharge of 142.8 per cent during the period May, 1915, to August, 1918.

From the foregoing comparisons of characteristics that affect erosion, it is seen that all are equally favorable or more favorable to erosion in the case of Bay Creek than for the North Forked Deer River, except that rainfall favored to a very slight extent greater erosion on the latter stream.

It follows that the enlargement of channel and increase in discharge due to erosion would apparently be somewhat greater on Bay Creek than on the North Forked Deer River in the same period of time. To accomplish a saving in the cost of construction of a channel on Bay Creek, a channel smaller than the required size might be constructed and the work of erosion allowed to enlarge it to the required size while the uncleared lands are being cleared and made ready for cultivation.

While the North Forked Deer River Channel more than doubled in cross-sectional area during a period of three years and three months, in order to be on the safe side it will be assumed that the channel of Bay Creek will increase in size from a cross-sectional area of 450 square feet to 804 square feet (the required size) during a period of four years. This is an increase of only 78.7 per cent in cross-sectional area, and an increase of only 109.5 per cent in discharge as compared with an increase of 101.2 and 142.8 per cent, respectively, for the North Forked Deer River Channel.

In columns 8 and 9 of Table 4 it is seen that the mean maximum depth for the North Forked Deer River Channel increased from 8 to 11.4 feet and the average top width from 36 to 57.2 feet. It is therefore reasonable to assume that the average maximum depth for the Bay Creek Channel would increase from 10 to 12 feet and the average top width from 55 to 79 feet. While the soil will stand at a slope of 1½ on 1, a slope of 1 on 1 should be used since the ditch can thereby be constructed more cheaply, and enlargement due to erosion will increase faster for the steeper slope, the velocity being sufficient to remove caved-in material.

The length of the proposed channel is about 7 miles. The earth to be excavated for the proposed channel would amount to about 616,000 cubic yards and for the required size of channel about 1,101,000 cubic yards, a difference of 485,000 cubic yards. If the cost of excavation were estimated at 9 cents per cubic yard, the difference in the cost of the two channels would be $43,650. From this it is apparent that a substantial saving could be effected by allowing the work of erosion to enlarge the channel to the required size. Some damage to crops on the cleared lands might be done during the period of enlargement, but it is believed that this would be offset, to some extent at least, by the saving in drainage taxes on lands in the district.

ORGANIZATION OF THE UNITED STATES DEPARTMENT OF AGRICULTURE

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