

THE EFFECT OF CUTTING OFF BENDS IN RIVERS

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INTRODUCTION

From very early times it has been believed that the height of floods in crooked rivers could be reduced by cutting off the bends and straightening the channel in order that the water would flow faster and not rise to such great heights. Although the results were usually beneficial, in some cases where they have been used cutoffs have increased damage in one locality while reducing it in another, thus possibly causing a net damage rather than a benefit. Since the cause of these unexpected effects was not well understood, a great deal of controversy arose over the desirability of improving flood conditions by bend cutoffs and this discussion has continued down to the present date. The problem is somewhat complex since there are a number of factors which must be considered. A number of discussions of the subject have been printed, the best probably being that of the late Professor G. W. Pickles [1], but all of them appear to omit some important factors. In this paper an attempt is made to cover all the most important ones. The treatment starts with the simplest case and then proceeds to the more complex ones.

EFFECT OF A CUTOFF WITH STEADY FLOW AND A NON-ERODIBLE CHANNEL.

From the standpoint of analyzing the effect of bend cutoffs, the simplest case is a single bend, where the material in which the stream flows is non-erodible, and the discharge of the stream is steady.

Consider, for example, the stream in Fig. 1, which flows around a bend with surface and bed profiles, before the cutoff is made, sloping uniformly as shown. If a cutoff is made across the neck of the bend, the bottom profile is changed to that labeled "River

Bottom After Cutoff", in which the elevations at the ends of the cutoff are those of the corresponding points on the original bend. The water surface below the lower end of the cutoff is at the same elevation as that below the lower end of the bend before the cutoff since it is determined by conditions downstream, which have not changed. Beginning at the lower end of the cutoff, the depths of flow are less than they were in the stream before the cutoff, the lowering gradually decreasing in an unstream direction as shown. The effect on the water surface of a cutoff in a non-erodible channel with steady flow is, therefore, only to lower the water surface up-

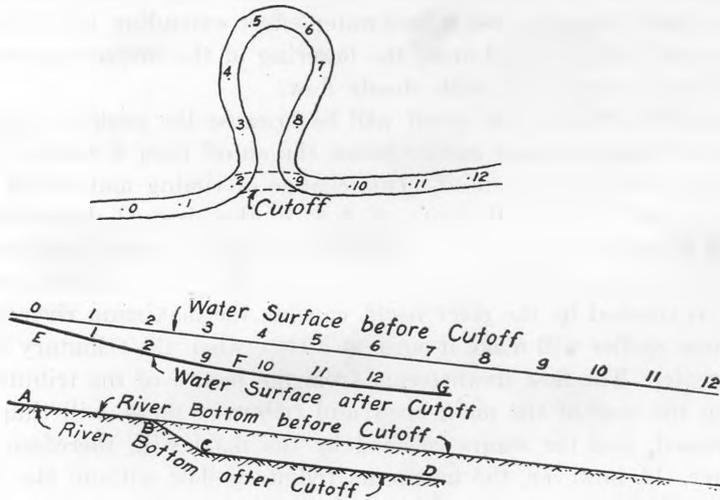


FIG. 1—EFFECT OF A CUTOFF IN A NON-ERODIBLE CHANNEL.

stream from the lower end of the cutoff, the amount gradually decreasing upstream. The magnitude of this effect can be readily determined by a backwater computation.

CUTOFFS WITH VARIABLE FLOW AND NON-ERODIBLE CHANNEL

If the flow of the stream is variable, as is usually the case in natural streams, storage effects enter in and modify the conditions described in the preceding case. If it is assumed that above the bend of Fig. 1 the bottom land was wide and, before the cutoff was made, it was flooded to the level shown in the initial profile

of the water surface, the cutoff would lower this water level somewhat, and the bottom land would not be flooded as deeply as before. If the inflow into the river from the tributaries above the cutoff is the same, both before and after the cutoff, and the storage in the bottom land is less after the cutoff, the rate of flow through the cutoff must increase in order to discharge the flow previously carried in addition to the amount supplied from this reduced storage. This increased rate of flow produces higher water levels in the stream downstream from the cutoff. It is also possible by engineering methods to approximate the amount of this increase in discharge and depth of water downstream [6]. This increased stage below would cause a backwater effect extending up through the cutoff, which would make the lowering of the surface upstream less than would occur with steady flow.

Another effect of the cutoff will be to cause the peak or highest stage of floods to come earlier below the cutoff than it would have if there had been no cutoff. This change of timing may either increase or decrease the rate of flow in the channel downstream from the flood. If there are tributaries below the cutoff that bring their maximum discharge into the river before the maximum rate flow is reached by the river itself, causing the maximum river flow to come earlier will make it come at a time when the tributary flow is greater. The flow downstream from the mouth of the tributary, being the sum of the main river and tributary flows, will thus be increased, and the stages reached by the flood will, therefore, be higher. If, however, the maximum tributary flow without the cutoff comes into the river after the maximum flow in the river was reached (a less common case), the cutoff, by causing the river peak to be earlier, would cause the tributary flow to come in at a time when the tributary flow was smaller and would, therefore, reduce discharge rates and stages downstream from the tributary. These synchronization effects would also have backwater effects upstream from the cutoff. Summarizing these possibilities, it may be said that the effect on the height of a flood of a cutoff in a non-erodible channel under variable flow conditions is to reduce the height upstream from the lower end of the cutoff, but probably not as much as would result if the flow was steady, because of storage and synchronization effects. Downstream from the cutoff, the result is a combination of the raising due to the greater discharge caused by

the reduction in storage above the cutoff and the increase or decrease of flow due to the peak synchronizations.

It should always be remembered that while these changes result from a cutoff, the magnitude of them is the important fact from a practical standpoint. In some cases, they may be large enough to be important and in other cases the magnitude may be insignificant, and can, therefore, be ignored. This can only be determined by quantitative studies.

EFFECT OF A SERIES OF CUTOFFS

The effect of a series of cutoffs on the same stream can usually be determined approximately by adding the effects of the cutoffs determined individually. If the cutoffs are close together, the action is usually similar to the cutoff of a single large bend. For conditions of steady flow and non-erodible channel, the effects can be accurately determined by working a backwater curve upstream from the lower end of the cutoff farthest downstream in the same way as for a single cutoff. Where storage effects or synchronization of tributary flows are of considerable magnitude, the best solution may be obtained by the construction of a hydraulic model. In cases where changes take place in the stream bed, it may be necessary to run the models a very long time to simulate these conditions.

CHANGES IN ERODIBLE CHANNELS

The changes which take place in erodible channels due to cutting off bends may be divided into two classes (1) immediate changes, and (2) long-period changes. The first of these occurs immediately or within a short time after the cutoff is completed, and long period changes are those which take place gradually over a period of considerable length, in some cases over a very long period of years. Except for the local changes which may occur during the enlargement of the cutoff channel from the changed direction of the currents due to the cutoffs, and from the deposits of the material scoured from the cutoff, the immediate changes which occur in an erodible channel due to a cutoff are the same as those which would occur in a non-erodible channel, since there has been insufficient time for the other changes due to erosion to take place.

In discussing the long term changes, it seems best to treat the

general case first and then consider how it is sometimes modified by the existence of non-erodible controls, the presence of large sediment storage space, or by the presence of large streams which would carry off the sediment. For the general case, it may be assumed that a cutoff occurs in a single bend, as shown in Fig. 1, in a stream with erodible sand or gravel bed, where the stream before the cutoff was not changing its flow capacity substantially from year to year. Neglecting the effect of the material, if any, which was removed to produce the cutoff, the conditions in the stream immediately after the cutoff are the same as those in the case of the non-erodible stream previously discussed. The bed, ABCD, of the river after the cutoff given on Fig. 1, is reproduced in Fig. 2 and also the surface profile EFG. Consider first the reach

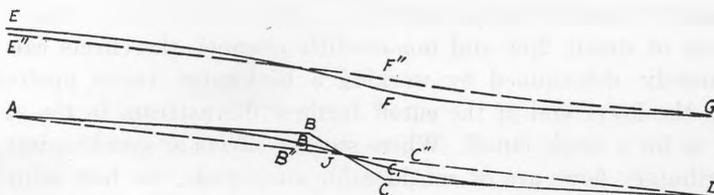


FIG. 2—EFFECT OF A CUTOFF IN AN ERODIBLE CHANNEL.

above the cutoff. The slope and velocity of the water above the cutoff is increased as compared to that existing before the cutoff was made, and the stream can carry a greater load than it was carrying. Because the stream at this point has a capacity to transport material in greater amount than the load brought down to it from above, the water picks up material from the stream bed and carries it downstream. Below the cutoff, however, the slope and velocity of the river is unchanged, and it is able to carry continuously only the amount carried before the cutoff. The excess over the load carried before the cutoff, which was taken up from the bottom upstream from the cutoff, is, therefore, deposited below the cutoff. This excess is not dropped immediately but is deposited in gradually decreasing quantities downstream from the cutoff. This results in a profile of the bed AB'C'D which causes some increase in slope downstream from the cutoff and a spreading of the deposits still further downstream. As the movement continues, the bottom downstream from the cutoff continues to be raised and this

effect also extends farther and farther downstream as shown by the profiles $AB''C''D$ and $E''F''G$. The cutting down of the stream bed upstream from the cutoff gradually increases in depth and extends farther upstream causing a lowering of the water surface elevation in this section to an elevation lower than that which would result from the cutoff if the bottom was non-erodible; the lowering effect also extends farther upstream. The raising of the bottom below the cutoff causes a raising of the water level downstream from the cutoff which extends a considerable distance downstream. After the river has had a long period of time to adjust itself, the maximum lowering above the cutoff occurs just upstream from the cutoff and approaches half the amount of the increased fall due to the cutoff. The maximum rise of water surface occurs just below the cutoff and approaches half the increased fall.

The foregoing discussion gives the results for the most general cases, but special circumstances sometimes exist which change the

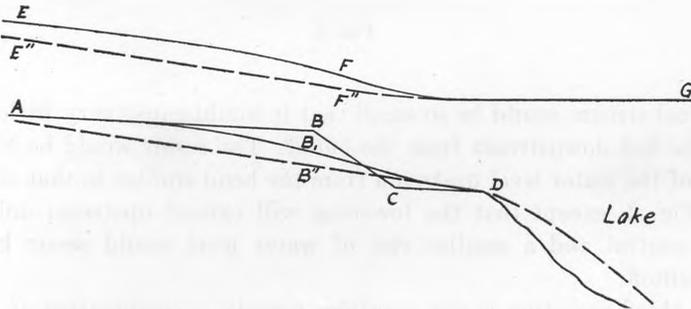


FIG. 3

situation sufficiently to produce quite different results. For example, if there was a large lake just downstream from the cutoff, as shown in Fig. 3, the sediment taken up from the bed upstream from the cutoff would be deposited without raising the river bed appreciably at the lower end of the cutoff. In this case, there would be little rise of the water surface below the bend, but the lowering of the bed upstream from the bend would be larger than in the general case shown in Fig. 2. A similar result would occur if the stream in which the cutoff occurs discharges just below the cutoff into a large stream which can carry away the sediment brought in. The same effect would also be produced by a rapids or waterfall in the stream just below the cutoff.

Another condition would result if there was a dam, rapid, or waterfall across the river bed just upstream from the cutoff, and normal river conditions existed downstream from the bend as shown in Fig. 4. Under these circumstances, the river bed upstream from the cutoff would be lowered only to this control and the quantity of material moved downstream in excess of that carried by the

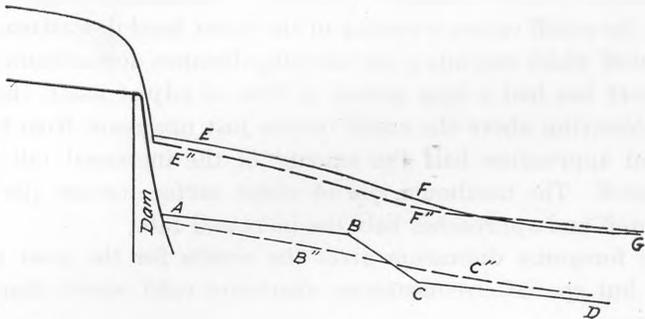


FIG. 4.

normal stream would be so small that it would cause very little rise in the bed downstream from the cutoff. The result would be lowering of the water level upstream from the bend similar to that shown in Fig. 2, except that the lowering will extend upstream only to the control and a smaller rise of water level would occur below the cutoff.

A third variation is also possible; namely, a combination of sediment storage capacity, larger stream, or waterfall downstream from the cutoff, and a dam, rapid, or waterfall just upstream as shown in Fig. 5. In this case, the water surface upstream from the cutoff would be lowered considerably up to the control, beyond which there would be no effect, and would be raised a small amount down to the control downstream. The farther these controls are from the cutoff, the more nearly these conditions will approach those shown in Fig. 2.

APPLICATION OF THE FOREGOING PRINCIPLES

Probably the most important aspect to be considered in applying the foregoing principles is the time factor. For engineering purposes, it is usually necessary to apply the principles quantitative-

ly. A very important question is "How rapidly will the change take place?" If it will become important in fifty years or less, it will probably be of interest to the engineer, but if it will not reach noticeable magnitude for several hundred years, it will be of interest to the geomorphologist only. The principles will be the same, but the significance of the action will be different.

In non-erodible channels, the changes will take place as soon as the cutoff occurs. Under favorable conditions, the changes resulting from bed movement can take place with relative rapidity, and become important in a few years. Under others, they may take centuries to become noticeable. In order to predict future conditions it is necessary to make quantitative solutions of this rate of change. This is frequently difficult because our knowledge of the laws of sediment transportation is not satisfactory. In general, changes on streams with steep slopes carrying heavy sediment concentrations take place relatively quickly, while those in flat streams

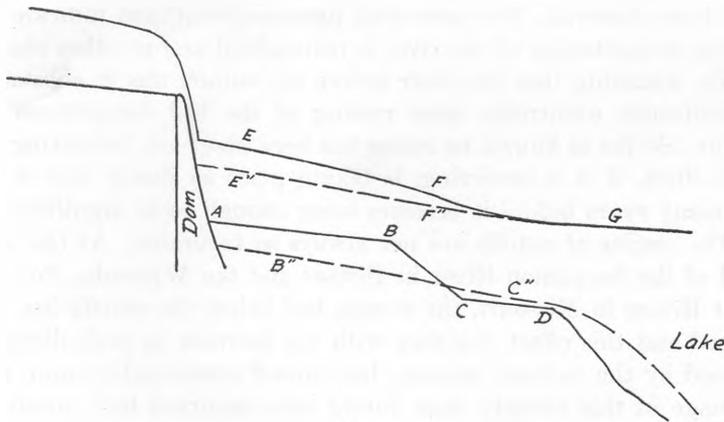


FIG. 5.

carrying light sediment loads take place slowly. The science of sediment transportation is advancing so rapidly that there is reason to hope that in a few years much better solutions will be possible. It is believed, however, that for these better solutions a knowledge of the basic principles herein described will be as necessary as they are today.

EXAMPLES OF THE EFFECT OF CUTOFFS

A famous example of cutoffs are those on the Tisza River in Hungary [2]. Here 112 cutoffs were made, shortening the river 283 miles in an original length of 746 miles, or 32%. This work was carried out nearly a century ago. As the cutoffs were accompanied by extensive levee construction, the effect of the cutoffs on discharges cannot be separated from the effect of the levees. The river bed has been lowered at various points as much as 7.4 feet. Because of the presence of the Danube River just below the cutoffs, no rise of the bottom downstream from the cutoffs has occurred.

To citizens of this country, the most interesting and important examples of cutoffs are those on the Mississippi River. Since 1929, 15 cutoffs have been made, reducing the length of the river by 140 miles. Between the mouth of the Arkansas River and Baton Rouge, there are thirteen cutoffs reducing the length 112.3 miles in 330.6 miles, or 35%. Flood heights at the upper end of this stretch have been reduced as much as 4.5 feet. Some increase in peak discharge has been observed. The principles previously outlined indicate that if the straightening of the river is maintained and no other changes made, assuming that the river before the cutoffs was in substantial equilibrium, eventually some raising of the bed downstream will occur. So far as known no rising has been observed, indicating that this effect, if it is occurring, is taking place so slowly that it may be many years before it becomes large enough to be significant.

The results of cutoffs are not always so favorable. At the lower end of the Sangamon River in Illinois and the Wyeconda, Fox, and Salt Rivers in Missouri, the stream bed below the cutoffs has been raised and this effect, together with the increase in peak discharge caused by the reduced storage, has caused considerably more flood damage in this vicinity than would have occurred had cutoffs not been made. Extensive cutoffs on tributaries to the Missouri River in Missouri and Iowa have resulted in a lowering of the beds of these streams and greater peak flood discharges. The cutoffs usually extended down to the Missouri River, and as this stream is large enough to store or carry away the increased load of sediment brought down, no rising of the bed of these tributary streams has resulted. A similar case of lowering of the stream bed occurred above the cutoff of a small stream near Cape Girardeau, Missouri [4]. The cutoff was near the Mississippi River, which prevented a

rise of the stream bed below the cutoff. Another interesting case of cutoffs was that which occurred 5 miles below Laguna Dam on the Colorado River. The river here had a slope of 1.2 ft. per mile and this cutoff shortened it 6 miles. In a period of 3 years, this caused a lowering of the tailwater at the Laguna Dam of 7 ft. Lowering farther upstream was prevented by the fixed crest of the dam, and the sediment removed due to the bed lowering in the five miles of river between the cutoff and the dam was not sufficient to cause an appreciable raising of the bed downstream from the cutoff.

IMPORTANCE OF THE TIME FACTOR

In conclusion, it is desirable again to point out the necessity of considering the time factor in cases of erodible channels, since failure to do so may lead to entirely unsound conclusions. The effects of a cutoff which are important are those which will occur in the time interval under consideration and depending on the particular conditions, these may resemble closely or may widely differ from those which will occur ultimately. In channels which will enlarge only slowly, the effects in the time under consideration are often close to the effects which will occur in a non-erodible channel. In considering the changes from the standpoint of a morphologist, however, the important changes are likely to more nearly approach the ultimate effect.

Under favorable conditions, changes in river levels may occur with great rapidity. Todd and Eliassen [5] mention a lowering of the bed of a 30 mile stretch of the Yellow River a maximum of 30 ft. and an average of 15 ft.; this took place in 12 hours with an average flow of 300,000 cfs, representing a movement of approximately a quarter of a billion cubic yards of material. Although this was probably not due to cutoffs, it serves to illustrate the rapidity with which rivers can change their bed levels due to a change in their sediment loads. Changes of somewhat comparable rapidity might result from bend cutoffs in some cases, while in other cases the change would be so slow that it would not be noticeable. The problem of predicting the rate of change due to cutoffs is likely, in many cases, to be more difficult than determining the nature of the change.

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