Stream Straightening Effects on Flood-Runoff Characteristics

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MANY Iowa rivers have been straightened and diked with the objective of achieving drainage and flood control on the riparian land. Although these methods have proved beneficial to the land along the reach straightened, they have often resulted in damage to the downstream landowners' property by increasing the discharge, thus forcing the downstream owners to repair or improve their part of the channel. Litigation among drainage districts often results, with downstream districts claiming partial reimbursement of the construction and maintenance costs from the districts upstream. This litigation often lasts for long periods of time and does not necessarily arrive at an equitable solution to the problem.

A study was therefore prompted at the Iowa State Water Resources Research Institute to evaluate the effects of channel straightening on the movement of flood waves. The objective of this study was to evaluate the effects of stream straightening and diking on the flow characteristics of storm runoff events. The flow characteristics used were the timing and magnitude of the peak discharge as the flow progressed downstream.

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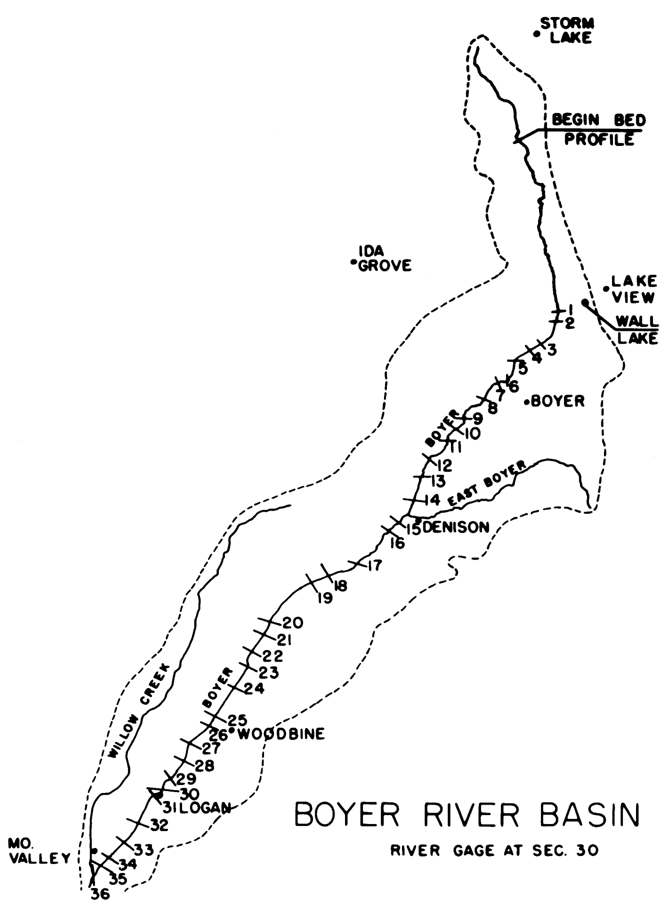

Fig. 1 Boyer River Basin in Western Iowa showing locations of channel cross-sections and rain gages.

DESCRIPTION OF THE BOYER RIVER

The Boyer River (Fig. 1), the second largest stream in western Iowa, with a drainage area of 1,188 sq miles, was selected for study. The Boyer River has undergone extensive straightening from southern Sac County to the Missouri River (Fig. 2), and its tributary, Willow Creek, has been realigned from southern Monona County to its confluence with the Boyer River. From its source in southern Buena Vista County, the Boyer River flows about 100 miles to the Missouri River. Measured along the line of stream flow before straightening in the early 1900's, the distance was about 250 miles. Perhaps 10 percent of its drainage area was forested, about 40 percent was in cultivation, and the rest was prairie or grassland. The average width of the Boyer flood plain through Harrison County was about one and a quarter miles. The surface slope of the valley, estimated by Dean (1913), varied from 20 ft per mile at the source to 1.85 ft per mile at the mouth of the river.

The duration of floods in the past was long, much of the flood plain was swampy before straightening because of the periodic overflowing of the river, and it was not uncommon for water to stand in some areas on the flood plain from spring until fall as a result of early spring floods. The first systematic measurement of discharge was made by Dean (1913) in 1905. He estimated a maximum discharge of 5,174 cfs at the Logan Mill Dam 15.5 miles above the mouth of the river. Information on the

TABLE 1. DRAINAGE AREAS AT SELECTED POINTS ON THE BOYER RIVER

Location	Drainage area, sq mi
Boyer River above Wall Lake (sec 1)	145
U.S.G.S. gage at Logan (sec 30)	871
Boyer River at mouth	1,188

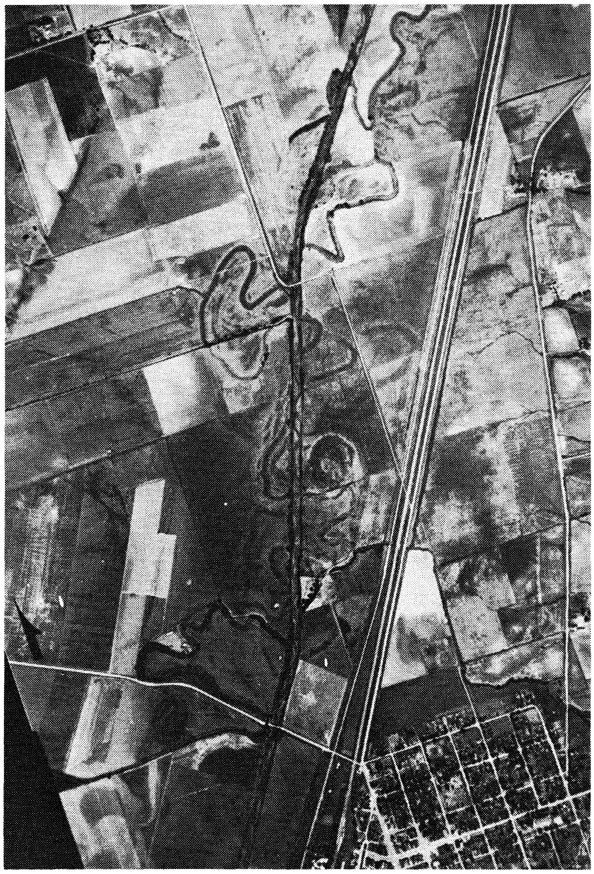

Fig. 2 A sample aerial photo indicating the degree of meandering and extent of channel straightening on the Boyer River.

flood wave is very sketchy, but according to Mr. James McCoid, then owner of the Logan Mill: "The crest of the wave reached Logan on July 4th or 5th, and the wave was more than a week in passing the mill." Before 1950, when the last straightening was completed, the maximum peak discharges were about 13,000 cfs, while the maximum discharges since 1950 have been about 23,000 cfs. In spite of the great increase in peak discharge since 1950, flooding is practically eliminated because of the increased channel capacity. A typical channel section of the Boyer River today is a steep-sided, flat-bottomed, straight ditch in contrast to the shallow and rather stable meandered channel in its natural state. The drainage areas at selected points along the river are given in Table 1.

PROCEDURE

The length of 58 miles of river from Wall Lake to Logan was used for this study for the conditions before and after straightening. Four stations (sections 1, 11, 22, and 30) dividing the length of 58 miles into approximately equal reaches were used as reference points. The location of the stations is shown in Fig. 1. The stage recorder operated at Logan by the U.S. Geological Survey was the only one available to obtain observed hydrographs on the river. Therefore, for the purposes of flood routing, the unit hydrographs developed by Campbell (1970) were used as inflow hydrographs at Wall Lake for both flood routing methods used in the study.

The kinematic (Brakensiek, 1966) and convex (SCS, 1964) methods of flood routing were used to study flood-runoff characteristics. The channel modification effects were measured for 1 in. of surface runoff over the drainage area above section 1. The effect of straightening was examined at the end of three reaches shown in Fig. 1 as sections 11, 22, and 30. The starting point for the flood routing was near Wall Lake. The derived unit hydrograph was used as inflow from excess precipitation above section 1. This inflow hydrograph was then routed to Logan through improved as well as through unimproved channel. Two conditions representing a partially straightened channel also were investigated. For the flood routing calculations, 30 cross-sections were used, with reach lengths varying from 4,000 ft to 27,000 ft. Stage-discharge relationships were calculated at each section by use of Manning's formula.

Three roughness coefficient values were used, 0.04, 0.06, and 0.10 for flood plain flow and a fixed value of 0.04 for channel flow before straightening. The n values assumed for present conditions were 0.03 for channel flow and 0.06 for flood plain flow. The value for the present channel coincides reasonably well with velocity measurements taken on the river to determine the roughness coefficient.

RESULTS

The results from both flood-routing methods indicate that the straightening and diking of natural streams increases the magnitude of the peak discharge and significantly shortens the time base of the discharge hydrograph. It also greatly reduces the time of travel of the flood wave down the river. The magnitude of these effects depends upon the length of the river involved and the characteristics of the river, such as shape of channel, degree of meandering, shape of flood plain as it affects the temporary storage capacity, vegetation on the flood plain as it affects the roughness or n value and slope of the valley.

Only the results from the convex routing method are presented here, but the results from the kinematic method agreed well with these. In discussing the results, the following terms will be used as defined:

Percent attenuation of peak discharge – the difference between peak discharge at a section downstream and that of the inflow hydrograph at section 1 by 100 divided by the peak discharge of the inflow hydrograph.

Percent increase of peak discharge after straightening – the increase in the peak discharge at a given location after straightening the river over that before straightening by 100 divided by the peak discharge at that location before straightening.

duration of flooding – the time that the discharge of the river at a given location is greater than the bankfull discharge at that location.

travel time of flood wave – the time from the beginning of rise of the river at section 1 to the beginning of rise at a given location downstream.

Percent reduction in travel time after straightening – the difference between travel time of the flood wave to a given location after straightening the river and that before straightening by 100 divided by the travel time of the flood wave to that location before straightening.

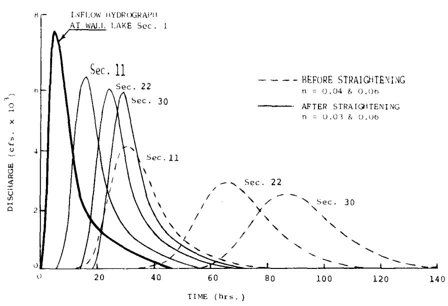

Fig. 3 Effect of complete channel straightening on the movement of a single flood wave consisting of 1 in. of surface runoff from above Wall Lake.

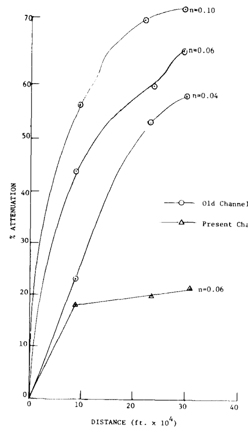

Fig. 4 Percent attenuation of peak discharge before and after straightening versus distance along river for 1 in. of surface runoff (Manning's n values indicated are for the flood plain).

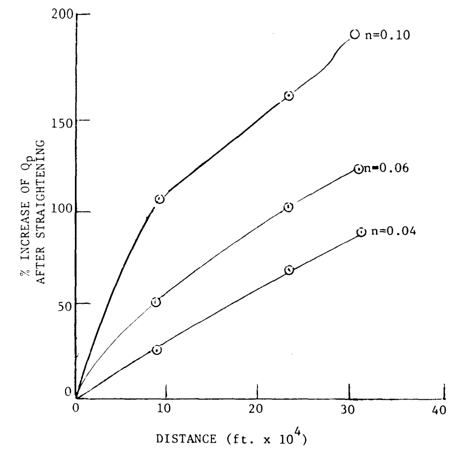

Fig. 5 Percent increase of peak discharge after straightening versus distance along river for 1 in. of surface runoff (Manning's n values indicated are for the flood plain).

The lines in the figures connecting values at sections 1, 11, 22, and 30 are there only to clarify the relationships among the various conditions in the figure and should not be taken as an indication of expected results at intermediate points along the river except in a general sense; local changes in the channel may cause variations from these smooth curves.

Changes in Peak Discharge

From Fig. 3 it is evident that there is considerable difference in reduction of the flood peak as it moves downstream for the before– and after–straightening conditions. Fig. 4 shows that, in the old channel, a single flood wave attenuates at a greater rate for some distance and then has a tendency to level off with a subsequent milder attenuation as it moves downstream, whereas in the new channel, though attenuation is small, it takes place at a more nearly uniform rate throughout the channel length. Attenuation measured at section 30 in the old channel is as much as 55 to 75 percent, whereas in the new channel, it is 20 to 30 percent.

Figs. 3 and 5 show the extent to which the peak discharge of a single wave moving from section 1 to section 30 is increased because of straightening. As is clear from Fig. 5, the increase in discharge depends on the roughness of the old flood plain. The increase in discharge at section 30, depending upon which roughness coefficient is used, varies from 90 to 190 percent for the hydrograph of 1 in. of surface runoff from the area above section 1. If the middle value of 0.06 for roughness coefficient is used, the peak discharge at section 30 is more than doubled for the given runoff volume as a result of straightening.

Duration of Flooding

Fig. 6 shows the duration of flooding along the river channel caused by the travel of a single flood wave from section 1 to section 30. The duration of flooding before straightening is about 30 to 40 hours throughout the channel length for 1 in. of surface runoff. Under the present conditions, very little flooding exists (and that only in the upper reaches, for 1 in. of surface runoff). From the reduced duration of flooding along the channel, it can be seen that downstream landowners have benefited more by the straightening operations, in terms of flood duration, than the upstream owners for the given runoff assumptions.

Travel Time

The effect of straightening on the travel time of the flood wave can be seen in Fig. 7. The reduction in travel time of the flood wave from section 1 to section 30 after straightening was about 60 to 70 percent, depending upon the roughness of the flood plain before straightening.

Partial Straightening

Two conditions to determine the effect of a partially straightened channel

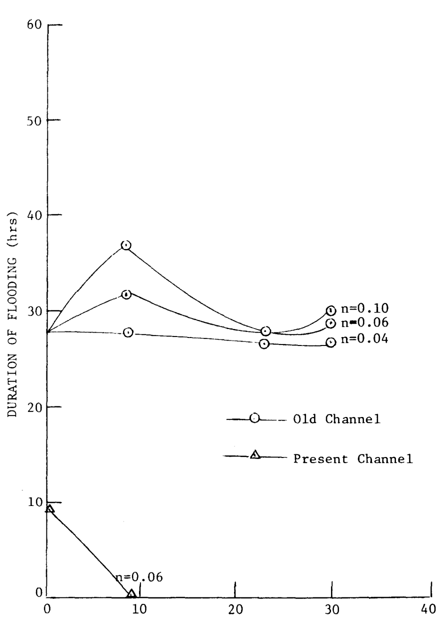

Fig. 6 Duration of flooding before and after straightening versus distance along river for 1 in. of surface runoff (Manning's n values indicated are for the flood plain).

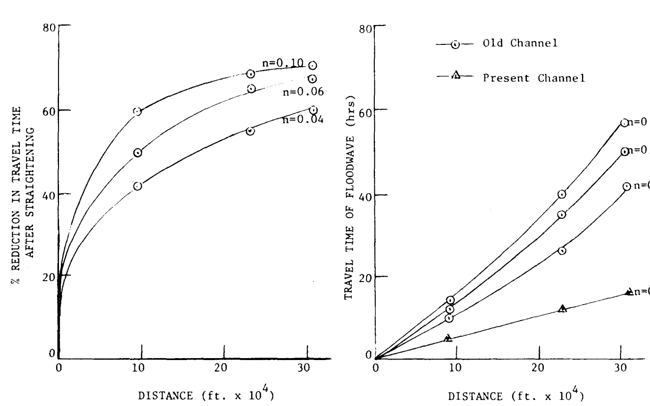

Fig. 7 Effect of channel straightening on travel time of flood wave along river for 1 in. of surface runoff above section 1 (Manning's n values indicated are for the flood plain).

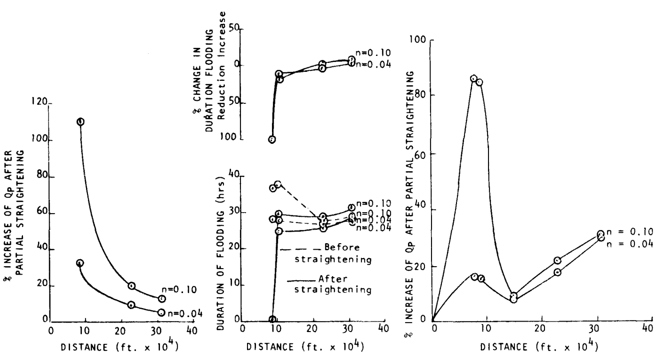

Fig. 8 (a, b) Curves showing hydrograph characteristics produced by straightening an upstream reach of the river and routing 1 in. of surface runoff from above Wall Lake. (c) Curves showing percent increase in peak discharge when the straightened river has one unimproved reach in the middle as obtained by routing 1 in. of surface runoff from above Wall Lake. (Manning's n values indicated are for the flood plain).

were studied; namely, the effect of straightening a short upstream reach of the river and the effect of leaving a reach unmodified along the straightened river. To formulate the first condition, a reach of 16 miles from section 1 to section 11 was assumed to have been modified. For the second condition, the 16–mile reach from section 10 to section 17 was assumed as unmodified, and the rest of the river was assumed straightened. This consisted of a straightened reach of 14 miles upstream and another straightened reach of 30 miles downstream from the unmodified reach of the river. The latter condition actually existed on the Boyer River during the 1940's.

Figs. 8a and 8b show the effect of straightening a short reach. A great percentage increase in peak discharge was obtained with a high n value for the original stream, but the effect soon disappeared as the wave passed through unmodified river. The increase in peak discharge for both the n values tested became negligible at section 30. The duration of flooding curves show that the duration of flooding decreased in the downstream end of the straightened reach because of increased channel capacity. But as the wave attenuated while traveling downstream, the duration of flooding increased and eventually reached its original value in the unstraightened reach. At section 30, the duration of flooding is nearly the same before and after the upstream straightening.

Fig. 8c shows the effect of an unmodified reach in the straightened river. The unmodified reach, even though short, provides tremendous storage, which can nullify the effects produced by the upstream straightening. As is indicated in the figure, 16 miles of unmodified river reduced the increase in peak discharge from 90 percent to 15 percent for the condition of high flood plain roughness coefficient. The increase in peak discharge at section 30 is 35 percent with high n and 30 percent with low n as compared with 190 percent and 90 percent respectively for complete straightening (Fig. 5).

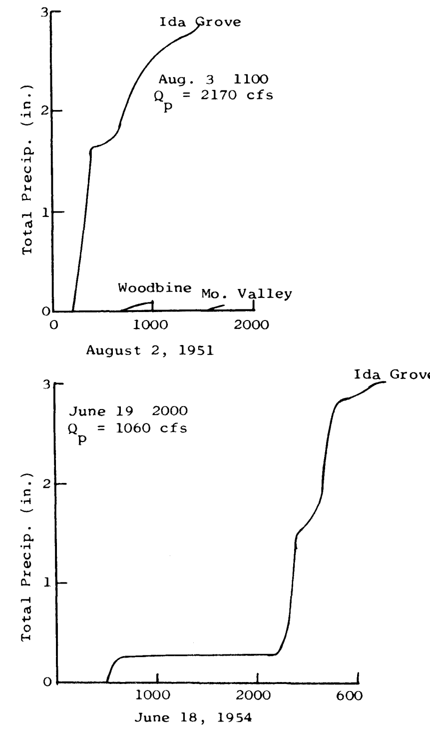

Fig. 9 Accumulated hourly precipitation for selected storms at several U. S. Weather Bureau stations in or near the Boyer River basin accompanied by the time and magnitude of the corresponding peak discharge on the Boyer River at the gaging station at Logan, Iowa.

Both change in peak discharge and duration of flooding indicate that the effect of straightening diminishes rapidly as the wave moves downstream; thus, the most affected areas from modifications are the ones along and immediately below the modified reach. More detailed results of the study may be found in Kumar (1970) and Campbell (1970).

COMPARISON OF ROUTING CALCULATIONS WITH FIELD DATA

Campbell (1970) obtained available precipitation data for selected storms producing flood hydrographs on the Boyer River and investigated the timing of precipitation with the discharge hydrograph at the U.S.G.S. gage located at section 30. From this data, the travel time of the flood wave from section 1 to section 30 under the present straightened conditions was estimated to be from 20 to 25 hours. The travel times obtained by both methods of computer flood-routing calculations for the present channel compared well with this estimate. The smaller runoff events, such as that illustrated in Fig. 9, correspond closely to the location of runoff used in the computer flood routing in which 1 in. of surface runoff over the

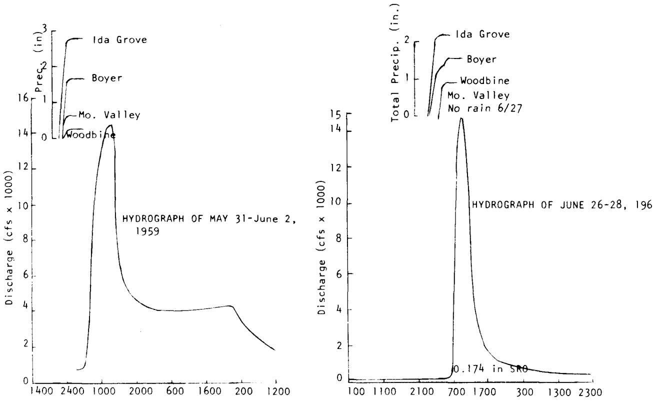

Fig. 10 Actual storm hydrographs on the Boyer River at the U. S. Geological Survey gaging station at Logan, Iowa, accompanied by accumulated hourly precipitation for the corresponding storms at several U. S. Weather Bureau stations in or near the Boyer River basin.

watershed area above section 1 was used. Time of travel decreases significantly with the larger runoff events because the large storms for which data are available are more general, and a greater portion of the runoff is due to lateral inflow along the river at various points, which initiates an earlier rise (Fig. 10).

Field data were obtained at sections 1, 11, 22, and 30 for one small runoff event, which occurred during this study on June 7-8, 1969, in the upper portion of the watershed above section 1. This storm occurred while the soil was dry and resulted in significant transmission losses in the river. Because of this, the observed peak discharges at sections 11, 22, and 30 were lower than the computed peak discharges; however, the travel time was affected less by the transmission losses. The travel time was 18 hours by the kinematic method, 20 hours by the convex method, and 25 hours by actual observation. Since we were primarily concerned with large flood flows that occur under wet conditions, no provision for subtraction of transmission losses was made in the convex routing procedure, although this was investigated briefly by the kinematic method.

SUMMARY

The effects of stream straightening and diking on river flow characteristics were determined for the Boyer River in western Iowa. Straightening has been done on the Boyer River, and several adjacent drainage districts have been formed. Problems have arisen concerning the distribution of cost assessments among districts along the river for construction, repair, and maintenance.

In this study, two flood-routing methods, the kinematic and convex methods, were used to obtain discharge hydrographs at several locations along the Boyer River. Several different flow conditions were used. Stream conditions, both before and after straightening as well as the effects of partial straightening, were investigated. Values of several flow characteristics were obtained from the flood-routing data generated, and were used as indicators of the effects of the stream straightening and diking. The flow characteristics used were:

1. peak discharge,
2. flood-wave travel time, and
3. duration of flooding.

Application of the flood-routing procedures used in this study to actual stream conditions on this scale needs to be studied in more detail where field data are readily available for comparison.

The major conclusions resulting from routing a hydrograph of 1 in. of surface runoff above section 1 are:

1. After straightening, the peak discharge was increased 90 to 190 percent, depending upon the flood plain n value used.
2. Flooding was eliminated after straightening, but lasted 30 to 40 hr before straightening.
3. Flood-wave travel time was reduced 60 to 70 percent after straightening the river channel.
4. The effect of straightening a small reach of the river diminishes rapidly as the flood wave travels through the unmodified reach.
5. An unmodified reach in the straightened river has a strong damping effect on the flood wave from the straightened river, thus greatly reducing the flood peaks.

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