Changes in the Configuration of a Stream Channel Resulting From the Construction of a Dam

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Abstract

Changes in the flow characteristics of a stream resulting from dam construction are shown to alter the transverse profile of Stevens Creek, which enters upstream from the Monroe Reservoir dam site in south-central Indiana. Depending on lake level, the stream segment which is situated at an intermediate elevation between the maximum and minimum levels of the lake experiences two totally different flow regimes. During periods of low lake levels, the flow characteristics of the stream are dependent on discharge. At periods of high lake levels the flow characteristics depend on the elevation of the lake. Independent of stream discharge and as a result of the new flow conditions induced by the dam, sedimentation occurs within the new wetted perimeter of the channel during periods of high lake levels. The amount of sedimentation depends on the stream discharge. The new sedimentation regime of the stream which is primarily one of deposition appears to be changing the morphology of Steven's Creek transverse profile by making the profile both narrower and deeper in appearance.

In geomorphic studies, the construction of a dam represents an abrupt man-induced environmental change that significantly alters both the hydrology of the river and the landscape. Besides drowning a portion of the existing river valley, a reservoir induces changes in both the upstream and downstream environments of the catchment basin. Recent studies, stressing fluvial processes, indicate that many aspects of stream morphology and associated landforms are in a quasi-equilibrium with the environment. Because of the disruption in the pre-dam environment, adjustments should occur in the morphology of the stream channels directly affected by the backwaters of the dam. These form adjustments are expected since numerous variables, especially flow characteristics, will change once the dam is functioning.

Completed in 1965, the Monroe Reservoir catchment area in south-central Indiana provides an opportunity for study of incipient and extended changes in the transverse profiles of streams within zones directly affected by the backwaters of dams. The specific stream chosen for investigation, Stevens Creek, represents a general example of a stream flowing into a reservoir. Stevens Creek flows into the northwestern portion of Lake Monroe and at the investigation site, the stream bed elevation is 541 feet. This elevation is an intermediate elevation between the regular pool lake level of 538 feet and maximum flood level of 556 feet. When lake levels are less than 541 feet, the stream dynamics of Stevens Creek are similar to pre-dam conditions even though its base level has been raised.

When Lake Monroe's level is greater than 541 feet, the stream at the station site is directly affected by the backwaters of the lake. It is during these periods of high lake levels that major adjustments in the transverse profile should occur due to the major changes in flow characteristics of the stream. Between the study period from October 1965 to July 1969, the lake level fluctuated between a maximum of 548 feet and a minimum of 535 feet, thus affording diverse flow conditions at the investigation site.

At-A-Station Hydraulic Geometry for Lake Levels Less Than 541 Feet

Utilizing data collected at the Stevens Creek Station, the adjustments of stream width, depth, and velocity to discharge fluctuations are described by the following three equations [1] where Q represents discharge, and w, d, and v stand for the surface width, the mean depth, and the mean velocity of the stream:

$$[1] \qquad \begin{aligned} w &= 25.11Q^{0.07} \\ d &= 0.51Q^{0.26} \\ v &= 0.08Q^{0.66} \end{aligned}$$

These equations were computed using discharge data ranging from 2.22 to 153.74 cfs. These equations derived through regression analysis indicate that for any given increase in discharge, velocity increases at the greatest rate and channel width increases at the lowest rate. These adjustments of width, depth, and velocity to discharge fluctuations are of the general form found in other recent studies (2).

Along with the measurement of stream discharge, samples of suspended sediment load were obtained at the Stevens Creek Station for a wide range of discharges and subjected to both size and weight analysis. The average suspended sediment load for Stevens Creek for three different discharge conditions were:

[2]
low discharge (2.22 cfs)— 3.2 mg/1
moderate discharge (21.33 cfs)— 10.7 mg/1
high discharge (153.74 cfs)—965.2 mg/1

From the observation of chains set within the stream channel, the velocity associated with the stream discharges are sufficient to prevent deposition of the suspended load at the Stevens Creek Station over an extended period.

At-A-Station Hydraulic Geometry With Lake Levels Greater than 541 Feet

During the study period, the lake level was greater than 541 feet on 11 different occasions. The maximum time period in which the lake was continually over 541 feet was 21 days, while the maximum lake level reached was 547.6 feet. With lake levels greater than 541 feet, the flow characteristics of Stevens Creek are altered by the backwaters of the lake. During these periods of high lake levels at the

study site, Stevens Creek experiences completely different flow characteristics than at low lake levels. As a result, the 3 previous at-a-station equations [1] are not valid for the periods when the lake level is greater than 541 feet.

For periods of high lake levels, the adjustment of the stream to width, depth, and velocity changes is primarily dependent on the lake level and not on stream discharge. With high lake levels, the stream channel at the study site becomes a portion of the lake itself causing the waters within the channel to flow at velocities less than 1 fps. During these periods, the mean depth and width of the creek fluctuate as the lake level changes while the velocity of the stream in the "lake portion" remains at a fairly low ebb (less than 1 fps).

Because this reduced velocity remains fairly constant whenever Lake Monroe is above the 541 foot level, the post-dam dynamics of Stevens Creek, at the study site, are different than the normal adjustments expected in a free-flowing stream condition. However, the velocity rates and sediment load of Stevens Creek above the reservoir level are unaffected by the variations of the lake levels. Consequently, the inundated "lake portion" of the Stevens Creek channel receives a continuous supply of suspended sediment during periods of lake levels greater than 541 feet from the upstream segment of the creek. With the low velocities within the "lake portion" of the stream and the continuous incoming sediment from upstream, deposition would be expected to occur. These sediments, if deposited within the reach of Stevens Creek that is temporarily under water, should alter the morphology of the stream channel over a period of time (Fig. 1).

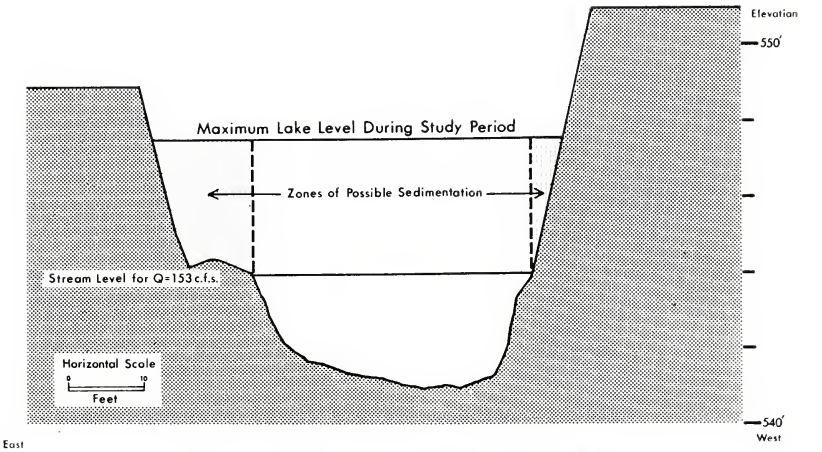

FIGURE 1. *Steven's Creek channel cross section.*

Utilizing the samples of suspended sediment [2], the amount of sedimentation that would occur within the temporarily flooded portion of the channel was computed using Stoke's Law. Accordingly,

the following amounts of sedimentation are expected when the free flowing upstream portion of the creek is experiencing the following discharges:

low discharge (2.22 cfs)— 17 kg of sediment/24 hours
[3] moderate discharge (21.33 cfs)— 560 kg of sediment/24 hours
high discharge (153.74 cfs)—316,000 kg of sediment/24 hours

While the amount of sediment for the high discharge appears extremely high, previous studies of other small stream basins have produced similar results (1).

Expected Morphology Changes

Prior to the existence of Lake Monroe, the present backwater reach of Stevens Creek was never characterized by near-zero water velocities under the constraints of low frequency (large discharges) stream flows. Pre-dam conditions for Stevens Creek probably approximated the relations expressed by the three at-a-station equations [1] for all in-bank discharges. Little, if any, sedimentation occurred during the pre-dam period, even though large amounts of sediment were present as the stream velocities were generally sufficient to keep the sediments suspended. Actually, evidence during the high discharges suggests that channel scour was the general case, and this was an important factor in determining the stream channel morphology. Under post-dam conditions, when the reservoir levels are high, it is possible to experience large sediment concentrations, low velocities, and small discharges. During these periods of high lake levels, the whole wetted perimeter of the channel is exposed to sedimentation. Depending on the upstream flow characteristics, anywhere from 17 kg to 316 metric tons of sediment can be deposited on the wetted perimeter of the channel during a 24-hour period [3].

The wetted stream perimeter of Stevens Creek is smaller for a given discharge at low lake levels than at high lake levels (Fig. 1). It is during these low lake level periods that possible fluvial erosion conditions exist at the station. Under the present conditions of stream flow, the potential of stream erosion is higher under low reservoir level conditions where there is a smaller wetted perimeter. As the channel adjusts to post-dam flow regimes, the transverse profile of Stevens Creek morphologically will appear to become deeper and narrower (Fig. 1). This form change results from the deposition of sediment within the larger channel during high lake levels, while the erosion of channel materials is confined to the smaller wetted perimeter during the periods of low reservoir levels. This will produce an illusion of stream entrenchment, when in actuality the form of the narrow, deep channel is primarily a result of deposition.

Summary and Future Research

With the further evidence that fluvial processes adjust rapidly to the flow characteristics of streams, it is possible to apply hydrological laws in order to predict geomorphic changes. The application

of Stokes' Law, along with the consideration of the flow and channel characteristics of Stevens Creek, suggests that in the intermediate segments of the channel which are directly affected by the backwaters of the lake, a substantial morphological change in the channel profile is occurring. This change is a direct result of the construction of the dam. While this morphological change is somewhat limited in its areal extent, numerous studies concentrating on other affected hydrologic variables (shorter channel lengths, higher water tables) might uncover other morphological changes resulting from the dam construction. The sum of these minor changes could alter the present landscape significantly. One result of such studies could be that the geomorphologist could assume a more important role in predicting environmental changes induced by dams and other man-made projects.

Acknowledgments

The research reported in this paper was partially supported by the Water Resources Program at Indiana University. All the analyses of sediment were done by the United States Geological Survey—Indianapolis Division.

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