CHANNEL GEOMORPHIC RESPONSES TO DISTURBANCES ASSESSED USING STREAMGAGE INFORMATION

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INTRODUCTION

An understanding of channel geomorphic responses to various human-caused and natural disturbances is important for effective management, conservation, and rehabilitation of rivers and streams to accommodate multiple, often conflicting, needs. For example, channel changes may have implications for various needs including water supply, infrastructure, navigation, and habitat. Human-caused disturbances include reservoir construction and operation, and channelization. Natural disturbances include floods and droughts. Possible geomorphic responses of a channel to disturbances include channel-bed erosion or deposition, channel widening or narrowing, and channel straightening.

Frequently, information documenting the geomorphic responses of channels to disturbances is lacking. Streamgages typically provide the only source of continuous, long-term streamflow and channel geomorphic information for the locations being monitored. Additionally, as determined by local conditions, the geomorphic information provided will be representative for some distance upstream and downstream from the gage. An analysis of streamgage data can provide information on the spatial (location, type, magnitude) and temporal (timing, duration, trend) dimensions of channel geomorphic responses to disturbances. Such information can be valuable as a primary or supporting source of evidence to document geomorphic change. Moreover, such information can be used to estimate rates of geomorphic processes, to reconstruct historical channel conditions, to determine the causes of channel change, to estimate future channel changes, and to assess channel recovery following disturbance (Juracek and Fitzpatrick, 2009; Bowen and Juracek, in review).

In this paper, the results of several studies in Kansas that used U.S. Geological Survey (USGS) streamgage information to investigate the geomorphic responses of channels to disturbances are presented. The examples provided demonstrate the use of streamgage information to document channel geomorphic responses to reservoirs, channelization, and floods. Given that the USGS currently operates a network of about 7,000 active gages in the United States using consistent methods, the techniques described here may have utility for geomorphic investigations nationally. Several thousand discontinued gages also provide historical information.

METHODS

Investigations of channel geomorphic responses to disturbances primarily were accomplished using two types of evidence derived from streamgage information—namely, changes in channel-bed elevation and channel width. Respectively, changes in channel-bed elevation and channel width were estimated using stage-discharge and discharge-width relations as explained in the following sections.

Determination of Channel-Bed Elevation Change: At any given location and time along a stream, a relation exists between stage and discharge. For gages these relations are quantified on rating curves and updated as necessary to accommodate changes in channel shape, slope, and other factors that affect the relation. Each rating represents a best-fit line through the measurement data (i.e., paired measurements of stage and discharge). Discharge measurements at, and stage-discharge ratings for, USGS gages are made using standard USGS techniques (Buchanan and Somers, 1969; Kennedy, 1984) with a typical accuracy of about ±5% (Kennedy, 1983; Sauer and Meyer, 1992).

By computing the stage that relates to a reference discharge for each rating curve developed during the entire period of record of a gage (and correcting to a common datum, if necessary), trends in the elevation of the channel bed can be inferred by plotting the resulting time-series data. Ideally, the reference discharge selected is a relatively low flow that is sensitive to change. Use of a low discharge minimizes the effects of variations in channel width on flow depth (Simon and Hupp, 1992). Juracek (2004) used the mean annual discharge for the period of record, whereas Williams and Wolman (1984) used the discharge exceeded 95% of the time. In the studies presented herein, the mean annual discharge for the period of record was used as the reference discharge to investigate possible changes in channel-bed elevation.

If the stage for the reference discharge (hereafter referred to as the reference stage) has a downward trend, it may be inferred that the channel-bed elevation has declined with time because of erosion. Conversely, if the reference stage has an upward trend, it may be inferred that the channel-bed elevation has risen with time as a result of deposition. An abrupt increase or decrease in reference stage may be indicative of a relatively rapid change in channel-bed elevation. The absence of a pronounced change or trend indicates that the channel bed has essentially been stable.

Determination of Channel-Width Change: Channel-width change was investigated through an analysis of discharge-width relations for a range of in-channel flows. For each gage site, discharge-width relations were grouped into approximate 5-year successive intervals to get a representative range of in-channel flows for each interval. The successive 5-year intervals then were compared to determine if substantial changes in channel width had occurred over time. Use of a range of in-channel flows potentially can provide an indication of channel-width changes at multiple heights within the channel (as opposed to just using the bankfull channel width).

Limitations of Streamgage Data: Several possible limitations may restrict or prevent the use of streamgage data to assess channel geomorphic responses to disturbances. First, for an area of interest, there may be an inadequate number of gages with sufficiently long periods of record. Second, an existing gage may not be ideal because it is located in a reach that is unrepresentative or essentially stable as a result of one or more human-caused or natural conditions. Third, discharge measurements made at different cross sections may be a concern because the potential variability introduced may affect interpretation of geomorphic change. For a comprehensive discussion of the potential limitations of using streamgage data for geomorphic applications, see Juracek and Fitzpatrick (2009).

RESULTS AND DISCUSSION

Reservoir Effects: Reservoir construction and operation can have a substantial effect on the stability of the river channel downstream from the dam. Reservoirs can trap and permanently store virtually the entire sediment load delivered from the upstream basin (Petts, 1979; Williams and Wolman, 1984). Thus, immediately downstream from a dam, a river's sediment load is greatly reduced. In addition, typical downstream changes in the flow regime include a reduction in the magnitude of peak flows and a possible increase in the magnitude of low flows (Williams and Wolman, 1984). In response, the downstream river may adjust in an attempt to re-establish an approximate equilibrium between the channel and the discharge and sediment load being transported. Possible adjustments include channel-bed erosion or deposition, channel widening or narrowing, and changes in channel pattern or shape.

Streamgage data were used to assess the stability of the Neosho River downstream from John Redmond Reservoir (completed in 1964) in east-central Kansas in response to concerns that the reservoir was causing channel widening. For two gages located downstream from the dam, long-term data on channel width, channel cross-sectional area, and flow velocity representing a range of in-channel flows were plotted against discharge in successive 5-year intervals. For the near-dam gage, located about 5 miles downstream, an initial period of modest channel widening followed by stability was indicated. At the downstream gage, located about 56 miles from the dam, no change in width was apparent; however, a decrease in channel cross-sectional area associated with an increase in flow velocity was indicated (Juracek, 2000).

An investigation of channel-bed elevation change downstream from 24 large reservoirs in Kansas indicated that channel-bed erosion was a common geomorphic response. The amount of channel-bed erosion ranged from negligible for a few sites to a maximum of about 9 feet for the Republican River downstream from Milford Dam in northeast Kansas. The gage sites for which channel-bed erosion of at least 1 foot was indicated were located within 4 miles downstream from the dam (Juracek, 2001).

An interesting example was the Smoky Hill River in central Kansas for which both a downstream and upstream geomorphic response to the presence of Kanopolis Lake (completed in 1948) was indicated. Before the dam was completed, a downstream increase in the reference stage of about 1 foot indicated deposition that may have been a result of the disturbance (and associated increased sediment load) caused by the construction of the dam. Once the dam was completed, the downstream reference stage decreased about 6 feet with most of the indicated erosion occurring during the first 30 years. During that 30-year period, the erosion was interrupted by an interlude of modest deposition that occurred during a prolonged drought in the 1950s (fig. 1). Upstream from Kanopolis Lake, changes in the reference stage indicated that the

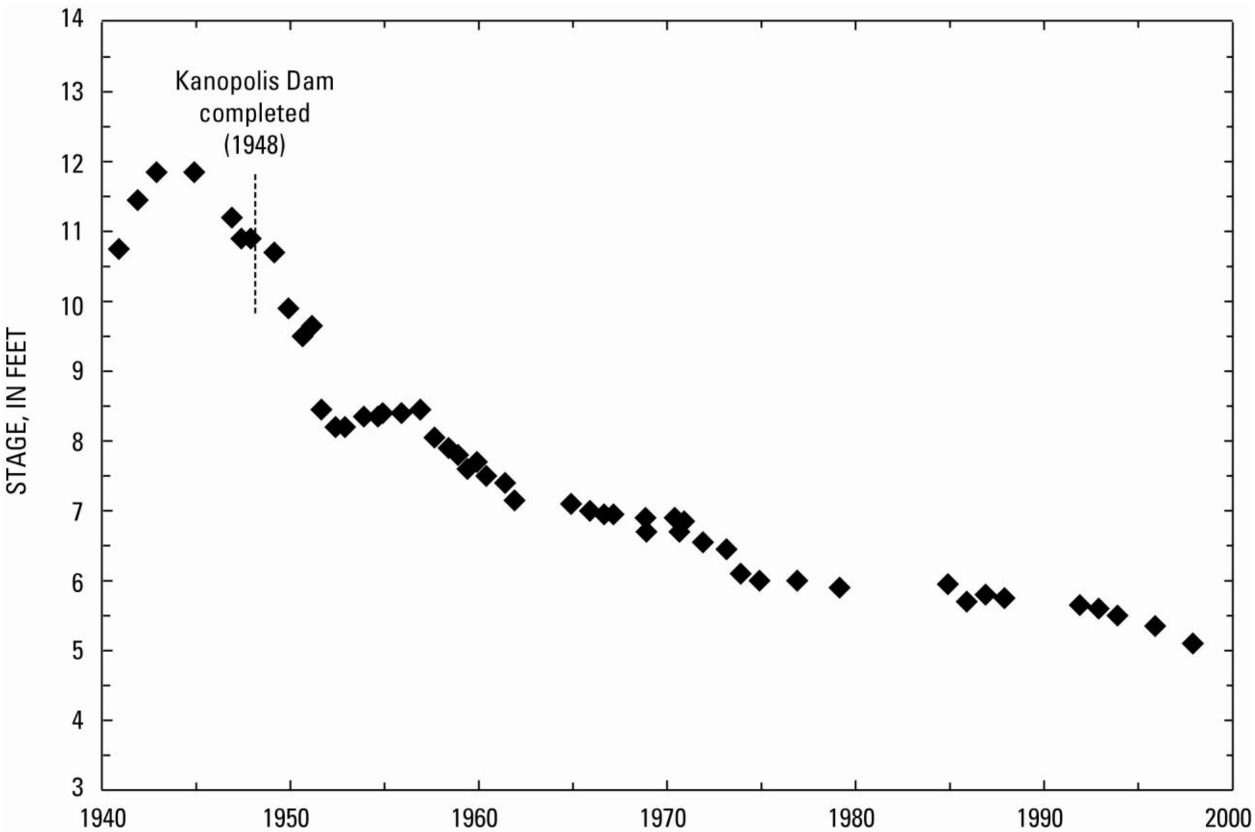

Figure 1. Change in stage for mean annual discharge (300 cubic feet per second) of Smoky Hill River near Langley, Kansas (gage number 06865500), 0.8 mile downstream from Kanopolis Lake, 1940-97.

channel bed slowly aggraded for several decades before stabilizing (fig. 2) (Juracek, 2001). The aggradation likely was a response to the artificial base level created by the reservoir.

Channelization Effects: Channelization typically involves several types of channel modification including realignment, widening, deepening, and straightening. Typically, channelization results in channel shortening that increases channel slope and flow velocity which can cause substantial channel degradation. The degradation can migrate long distances upstream from the original site of disturbance. In addition, channel aggradation may occur downstream.

Juracek (2004) investigated the geomorphic response of Soldier Creek, Kansas, to channelization using streamgage data. In the late 1950s, about 10 miles of the stream were channelized for the purpose of flood control in the vicinity of Topeka, Kansas. The project, which was completed in 1961, involved channel realignment, widening, deepening, and straightening. The channelization-caused disturbance resulted in channel-bed degradation that migrated several miles upstream.

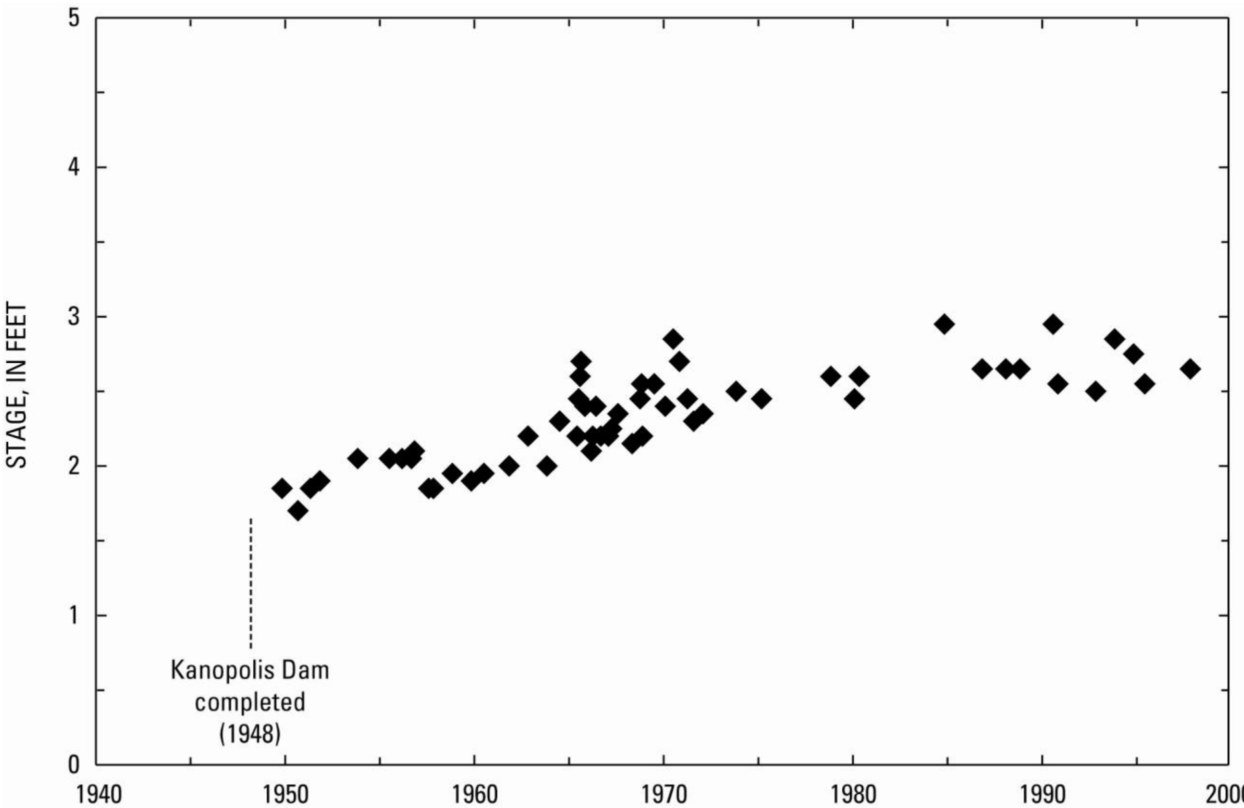

Figure 2. Change in stage for mean annual discharge (200 cubic feet per second) of Smoky Hill River at Ellsworth, Kansas (gage number 06864500), upstream from Kanopolis Lake, 1949-97.

At a gage located about 12 miles upstream from the upstream end of the channelized section of Soldier Creek, changes in the reference stage clearly indicated the geomorphic response of the channel to the downstream channelization (fig. 3). Initially, from 1958 to 1970, a relatively stable channel bed was indicated as the reference stage fluctuated in response to scour and fill processes. Following the construction of a low-water crossing downstream from the gage in 1971, the reference stage increased about 1.5 feet indicating deposition. Then, following the partial washout of the low-water crossing in 1978, the reference stage decreased about 6.6 feet by 1999 indicating a long-term period of channel-bed erosion (fig. 3). From 1978 to 1999, the decrease in reference stage indicated a channel-bed degradation rate of about 0.3 foot per year.

A question that sometimes arises is whether a decrease in stage with time for a specific discharge is caused by channel-bed degradation or another cause such as channel widening or increased flow velocity. In this case, the pronounced channel-bed degradation indicated by the progressive change in the stage-discharge relation (fig. 3) was confirmed by an assessment of temporal changes in the width-discharge relation for a range of in-channel flows. Specifically, a substantial decrease in the widths associated with the higher discharges (fig. 4) indicated that the channel had entrenched.

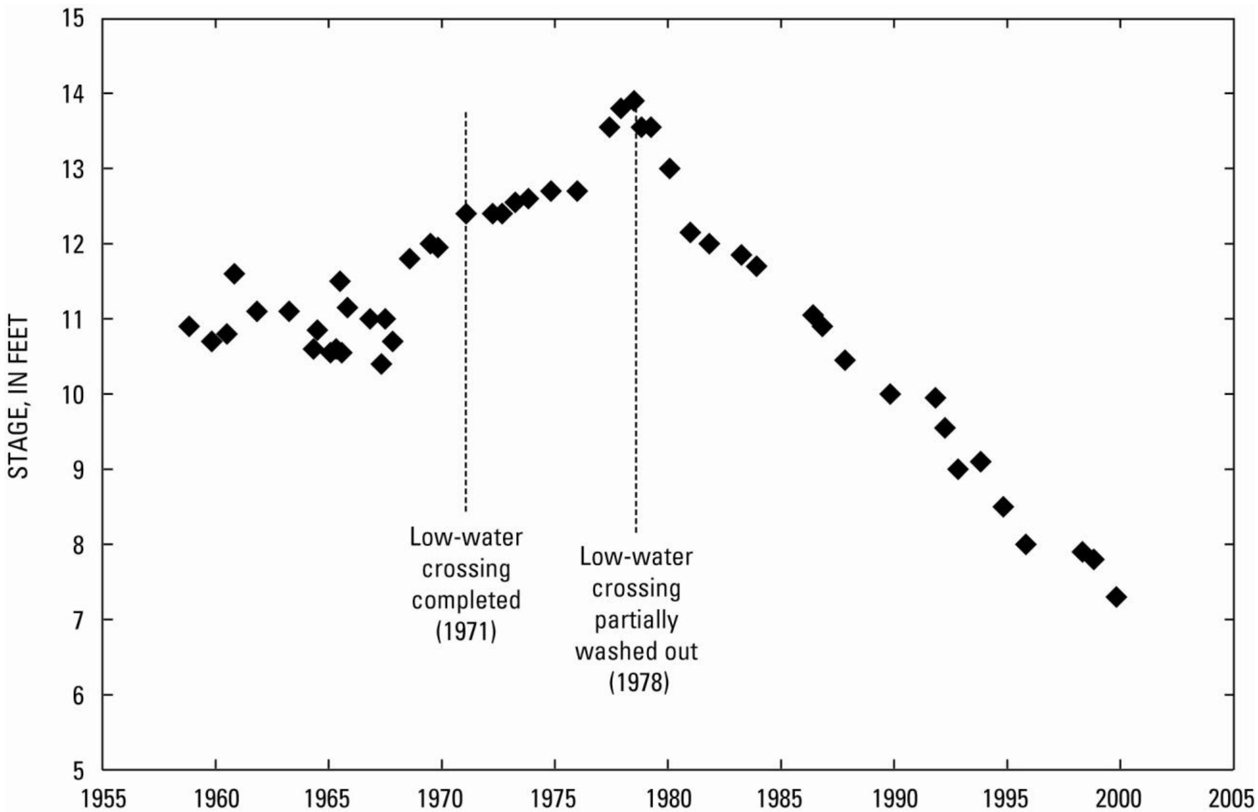

Figure 3. Change in stage for mean annual discharge (100 cubic feet per second) of Soldier Creek near Delia, Kansas (gage number 06889200), 1958-99.

The correspondence of the beginning of channel-bed degradation with the partial washout of the low-water crossing indicated that the crossing temporarily may have prevented the upstream migration of channel-bed degradation that would have reached the gage site as early as 1971 or as late as 1978. This translates to a total traveltime of 10 to 17 years for the degradation to migrate from the upstream end of the channelized section of Soldier Creek (located 12 miles downstream) to the gage site. Thus, the degradation migrated upstream at an average rate of 0.7 to 1.2 miles per year (Juracek, 2004).

Flood Effects: The geomorphic effectiveness of a flood can be defined as the amount of channel morphological change caused by the flood and the subsequent time required for the channel to recover (Wolman and Gerson, 1978). Geomorphic effects caused by floods, which may range from negligible to substantial, include channel widening, channel-bed erosion or deposition, and channel straightening (i.e., avulsion) (Baker, 1988; Knighton, 1998). Factors that can determine geomorphic effectiveness include channel bed and bank composition, channel morphology, channel slope, valley confinement, sediment load, flood duration, stream power, the temporal

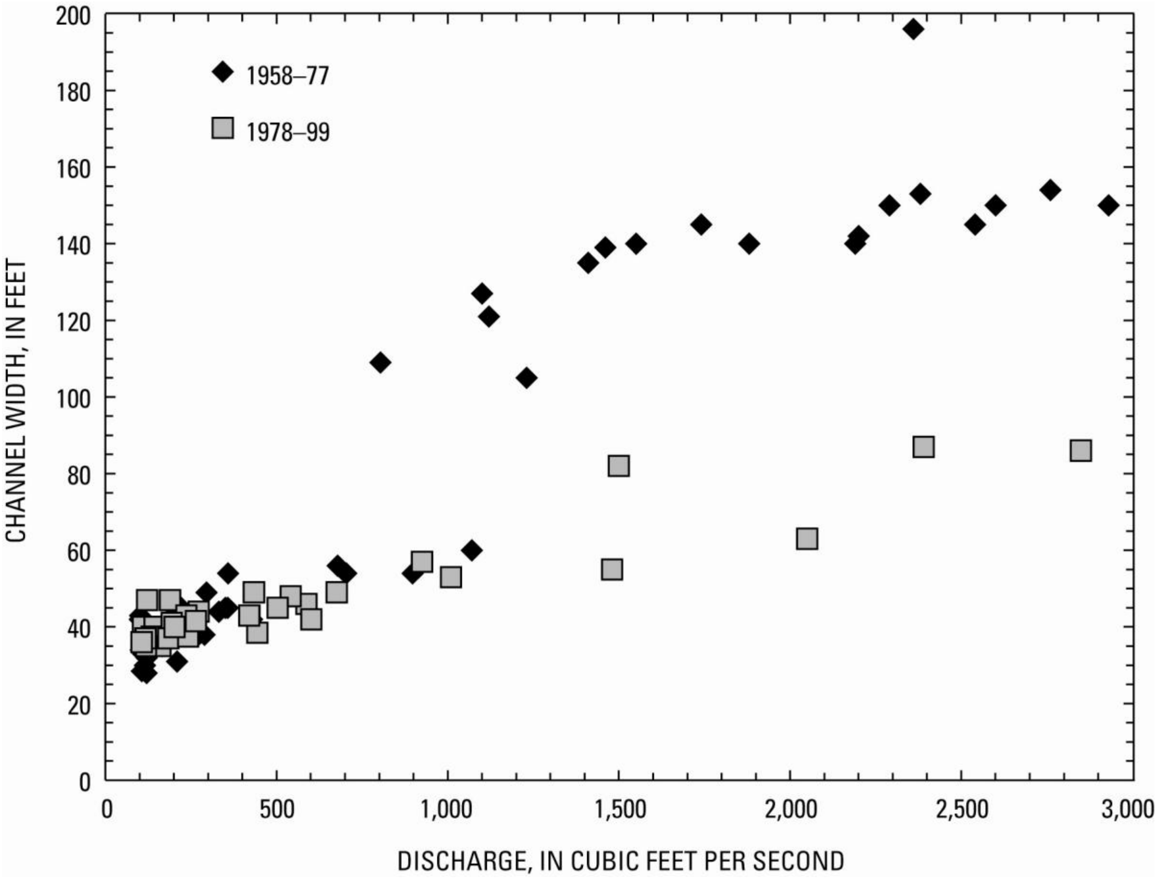

Figure 4. Relation between discharge and channel width for Soldier Creek near Delia, Kansas (gage number 06889200), 1958-77 and 1978-99.

ordering of floods, climate, and vegetation (Baker, 1988; Kochel, 1988; Costa and O'Connor, 1995; Osterkamp and Friedman, 2000; Emmett and Wolman, 2001; Fuller, 2007).

The geomorphic effects (short-term change and subsequent recovery) of the large 1951 floods in eastern Kansas were assessed using streamgage data for 23 sites in a study by Bowen and Juracek (in review). For the sites studied, the 1951 flood was the largest discharge for the period of record at least through the year 2000. Flood-related, channel-bed elevation change was indicated at 17 sites, and a substantial increase or decrease in bed elevation (defined as a change that was at least two times larger than the mean absolute bed-elevation change for the period of record) was indicated for seven sites. Substantial channel widening (at least 20 percent) was indicated for one site and possibly for two other sites.

At a gage located on the Kansas River at Wamego, Kansas, a sudden decrease in reference stage indicated that the channel bed was eroded about 1.5 feet as a result of the 1951 flood. Subsequently, the channel bed never recovered to its pre-flood elevation (fig. 5).

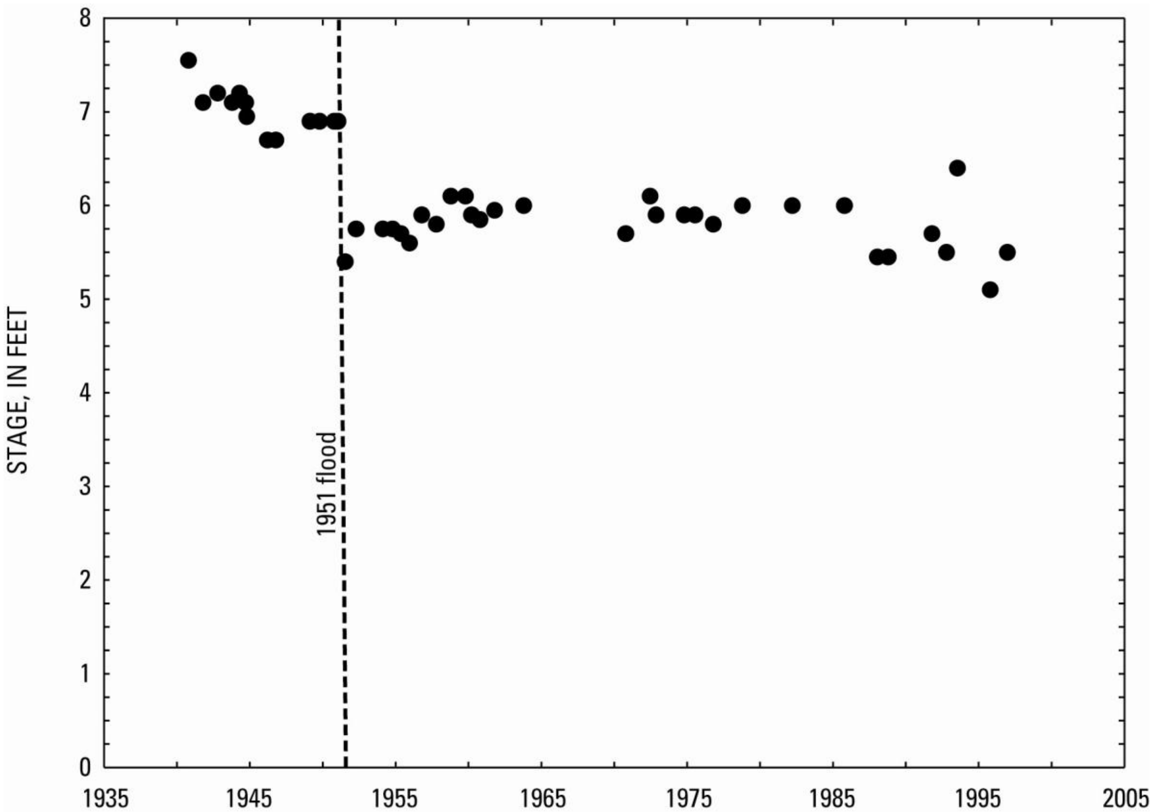

Figure 5. Change in stage for mean annual discharge (5,100 cubic feet per second) of Kansas River at Wamego, Kansas (gage number 06887500), 1940-2005.

At another gage located on the Kansas River at Lecompton, Kansas, channel widening of 150 feet or more (about a 20-percent increase) was indicated for moderate flows following the 1951 flood. Subsequently, during the late 1950s, the channel width for moderate flows decreased by as much as 50 to 80 feet (fig. 6). Due to a lack of high flows during the mid-1950s, channel-width changes at higher flows could not be assessed. Following the 1950s, channel width stabilized and remained relatively stable at least through 2007 (data not shown). Channel width did not completely recover to its pre-flood width.

SUMMARY AND CONCLUSIONS

Streamgage information can be used to investigate the geomorphic responses of channels to various human-caused and natural disturbances. In the examples provided, analyses of streamgage information indicated that disturbances such as reservoirs, channelization, and floods can cause substantial changes in channel-bed elevation and channel width. The use of streamgage information may be constrained because of possible spatial, temporal, and data limitations. Nevertheless, such information can be valuable as a primary or supporting source of evidence to document and explain geomorphic change. It is often the case that streamgages provide the only source of continuous, long-term channel morphology data for the locations being monitored. Thus, in the absence of other lines of evidence, streamgage information can

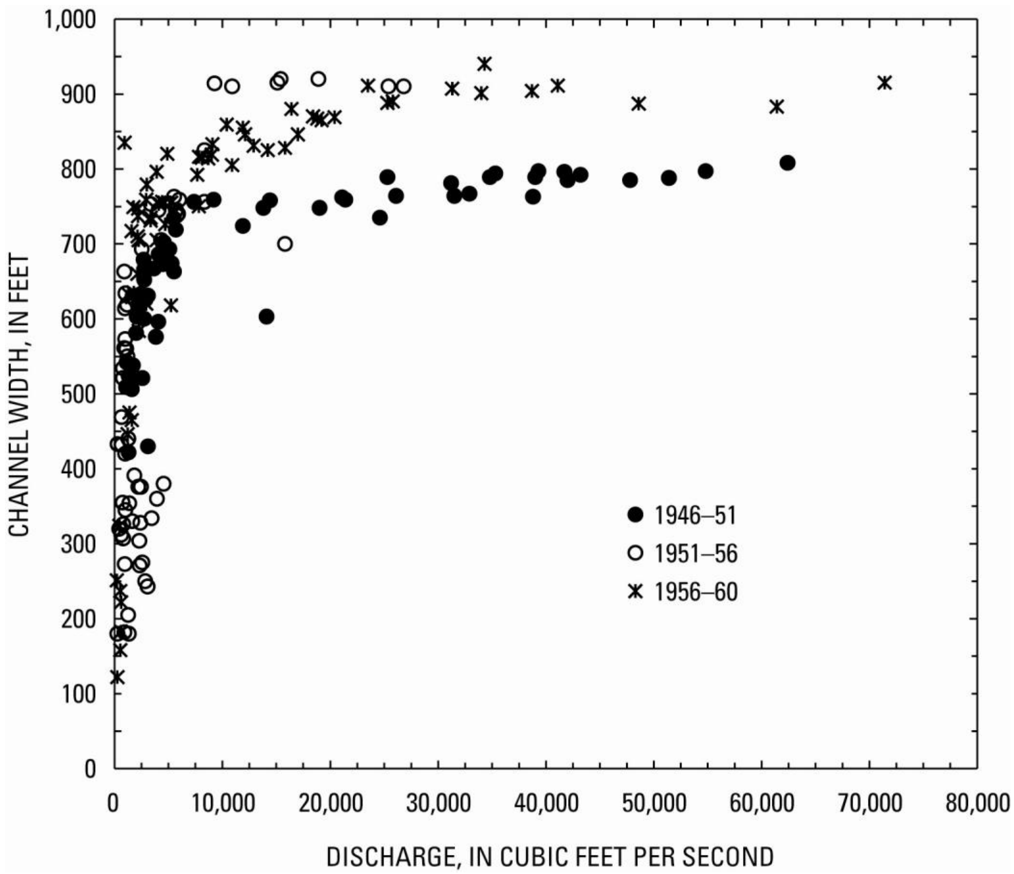

Figure 6. Relation between discharge and channel width for Kansas River at Lecompton, Kansas (gage number 06891000), 1946-51, 1951-56, and 1956-60.

provide an estimate of geomorphic change that otherwise might not be available or attainable. The knowledge gained from an analysis of streamgage information can contribute to an improved understanding of the geomorphic responses of channels to disturbances which, in turn, can enable more effective management of rivers and streams for various purposes.

REFERENCES

Baker, V.R. (1988). Flood Erosion. In V.R. Baker, R.C. Kochel, and P.C. Patton, eds., Flood Geomorphology. John Wiley & Sons, New York, pp 81-95.

Bowen, M.W., and Juracek, K.E. (in review). "Assessment of the geomorphic effects of large floods using streamgage data—The 1951 floods in eastern Kansas, USA," Submitted to Physical Geography.

Buchanan, T.J., and Somers, W.P. (1969). Discharge Measurements at Gaging Stations. U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter A8.

Costa, J.E., and O'Connor, J.E. (1995). Geomorphically Effective Floods. In J.E. Costa, A.J. Miller, K.W. Potter, and P.R. Wilcock, eds. Natural and Anthropogenic Influences in Fluvial

Geomorphology. American Geophysical Union, Geophysical Monograph 89, Washington, D.C., pp 45-56.

Emmett, W.W., and Wolman, M.G. (2001). “Effective discharge and gravel-bed rivers,” Earth Surface Processes and Landforms, 26, pp 1369-1380.

Fuller, I.C. (2007). “Geomorphic work during a ‘150-year’ storm—Contrasting behaviors of river channels in a New Zealand catchment,” Annals of the Association of American Geographers, 97, pp 665-676.

Juracek, K.E. (2000). “Channel stability downstream from a dam assessed using aerial photographs and stream-gage information,” Journal of the American Water Resources Association, 36, pp 633-645.

Juracek, K.E. (2001). Channel-Bed Elevation Changes Downstream from Large Reservoirs in Kansas. U.S. Geological Survey Water-Resources Investigations Report 01-4205.

Juracek, K.E. (2004). “Historical channel-bed elevation change as a result of multiple disturbances, Soldier Creek, Kansas,” Physical Geography, 25, pp 269-290.

Juracek, K.E., and Fitzpatrick, F.A. (2009). “Geomorphic applications of stream-gage information,” River Research and Applications, 25, pp 329-347.

Kennedy, E.J. (1983). Computation of Continuous Records of Streamflow. U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter A13.

Kennedy, E.J. (1984). Discharge Ratings at Gaging Stations. U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter A10.

Knighton, D. (1998). Fluvial Forms and Processes—A New Perspective. John Wiley & Sons, New York.

Kochel, R.C. (1988). Geomorphic Impact of Large Floods—Review and New Perspectives on Magnitude and Frequency. In V.R. Baker, R.C. Kochel, and P.C. Patton, eds. Flood Geomorphology. John Wiley & Sons, New York, pp 169-187.

Osterkamp, W.R., and Friedman, J.M. (2000). “The disparity between extreme rainfall events and rare floods—with emphasis on the semi-arid American West,” Hydrological Processes, 14, pp 2817-2829.

Petts, G.E. (1979). “Complex response of river channel morphology subsequent to reservoir construction,” Progress in Physical Geography, 3, pp 329-362.

Sauer, V.B, and Meyer, R.W. (1992). Determination of Error in Individual Discharge Measurements. U.S. Geological Survey Open-File Report 92-144.

Simon, A., and Hupp, C.R. (1992). Geomorphic and Vegetative Recovery Processes Along Modified Stream Channels of West Tennessee. U.S. Geological Survey Open-File Report 91-502.

Williams, G.P, and Wolman, M.G. (1984). Downstream Effects of Dams on Alluvial Rivers. U.S. Geological Survey Professional Paper 1286.

Wolman, M.G., and Gerson, R. (1978). “Relative scales of time and effectiveness of climate in watershed geomorphology.” Earth Surface Processes, 3, pp 189-208.