Journal of Hydrology (N.Z.) Vol. 22, No. 2, 1983

LONG-TERM CHANGES IN CHANNEL WIDTHS OF THE KOWAI RIVER, TORLESSE RANGE, NEW ZEALAND

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ABSTRACT

Widths of active channels of the lower 20 km of the Kowai River measured on aerial photographs were used to evaluate channel responses to increased sediment availability during 1943 to 1980. Hillslope erosion from a large storm in 1951 caused highly significant increases in channel width along upstream reaches; widening progressed downstream at an average rate of less than 1 km per year over the last three decades. During periods of channel aggradation, sediment was impounded upstream of gorges and bridges, whereas channel widths near these structures remained relatively narrow. Channel width also increased at the confluence of selected tributaries and downstream of an actively eroding glacial terrace. A cyclic component of channel width was obliterated along a 7 km reach by the downstream progression of sediment. Active channel widths of the Kowai River were influenced more by sediment loads than by stream discharge.

INTRODUCTION

Numerous variables are potentially useful for evaluating temporal changes in channels: channel depth and width, proportion of channel comprised of pools or riffles, longitudinal profiles, channel planform geometery, and bed composition and roughness. However, channel width is one of only a few variables that can be accurately and consistently measured on aerial photographs. Changes in channel widths may reflect changes in flow, sediment loads, land use in riparian zones and flood plains, and other factors that alter stream system dimensions. Schumm (1971, 1973, 1977) presents qualitative relationships between water or bedload discharge and channel or river adjustments as

$$Q_w = f\left[\frac{b, \lambda, d}{s}\right]$$

$$Q_s = f\left[\frac{b, \lambda, s}{d, p}\right]$$

where Q_w = mean annual discharge or mean annual flood,
Q_s = bed material transport,
b = channel width,
λ = channel wavelength,
d = channel depth,
s = gradient,
p = sinuosity, and
f = a functional relationship.

An increase in discharge or bed material transport, either individually or in unison, should cause an increase in channel width. This study examines the effects of sediment and streamflow on channel morphology by evaluating long-term changes in channel width of the Kowai River.

The Kowai River drains a 167 km^2 catchment of the Torlesse Range in the South Island of New Zealand (Fig. 1). The river and its tributaries have been a focal point for several studies related to sediment transport (Hayward, 1979, 1980; Griffiths, 1980b) and river processes (Blakely *et al.*, 1981; Beschta, 1983. Elevations range from nearly 2000 m in the catchment headwaters to 275 m where the Kowai River joins the Waimakariri River. Steep mountain slopes and hill country of the Torlesse Range occupy over two-thirds of the drainage basin at elevations mostly above 500 m. Average annual precipitation exceeds 1000 mm throughout most of the basin; major floods results from easterly or southerly storms. Glacial outwash deposits within the basin have been incised by the Kowai River throughout most of the lower 15 km. The channel pattern is predominantly braided.

CHANNEL WIDTHS (1943 TO 1980)

Active channels of the Kowai River were identified on sets of aerial photographs taken in 1943, 1960, 1972 and 1980, and active channel widths were determined at 0.1-km intervals (Fig. 2). Photographs also exist for the years 1965, 1966, 1973, and 1975; however, the coverage provided by these photographs was relatively incomplete, so the width measurements made are not included in Fig. 2. For a braided stream, the active channel width is the sum of distances across individual braids and exposed bed material. In comparison to the darker colors and tones associated with flood plains and vegetated riparian zones, the exposed bed material of the active channel has a high reflectance.

The downstream increase in active channel width of the Kowai River has much spatial and temporal variability (Fig. 2). Channel width has apparently responded to many processes and constraints, and features related to both structural controls and sediment availability are evident from this data.

Between the channel distances of 9 and 11 km, significant increases in channel widths occurred from 1943 to 1960, primarily because of aggradation during a large storm in April 1951. This storm, which had a recurrence interval of approximately 150 years (Beschta, 1983), mobilized large volumes of detritus and rock material from upper basin hillslopes. Extensive channel aggradation occurred throughout the upper reaches of

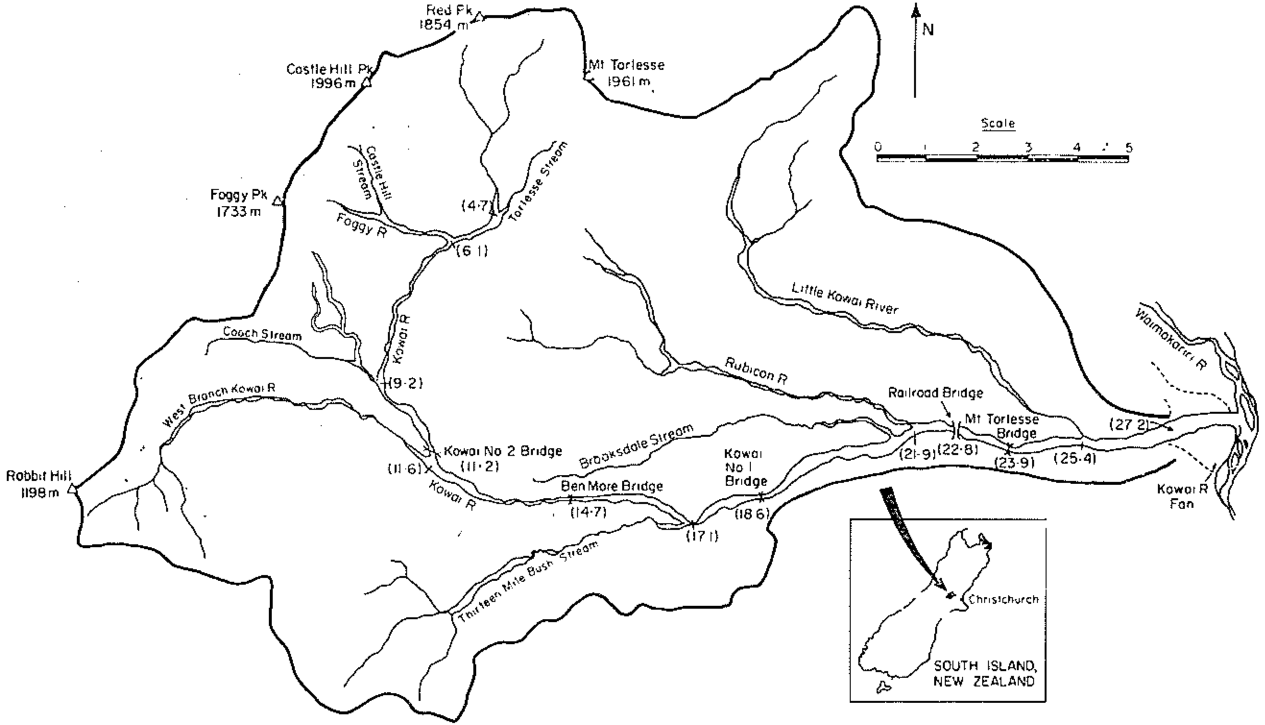

FIG. 1—Kowai River basin, South Island, New Zealand. Distances (km) downstream are measured from the catchment divide and shown for selected locations along the Kowai River.

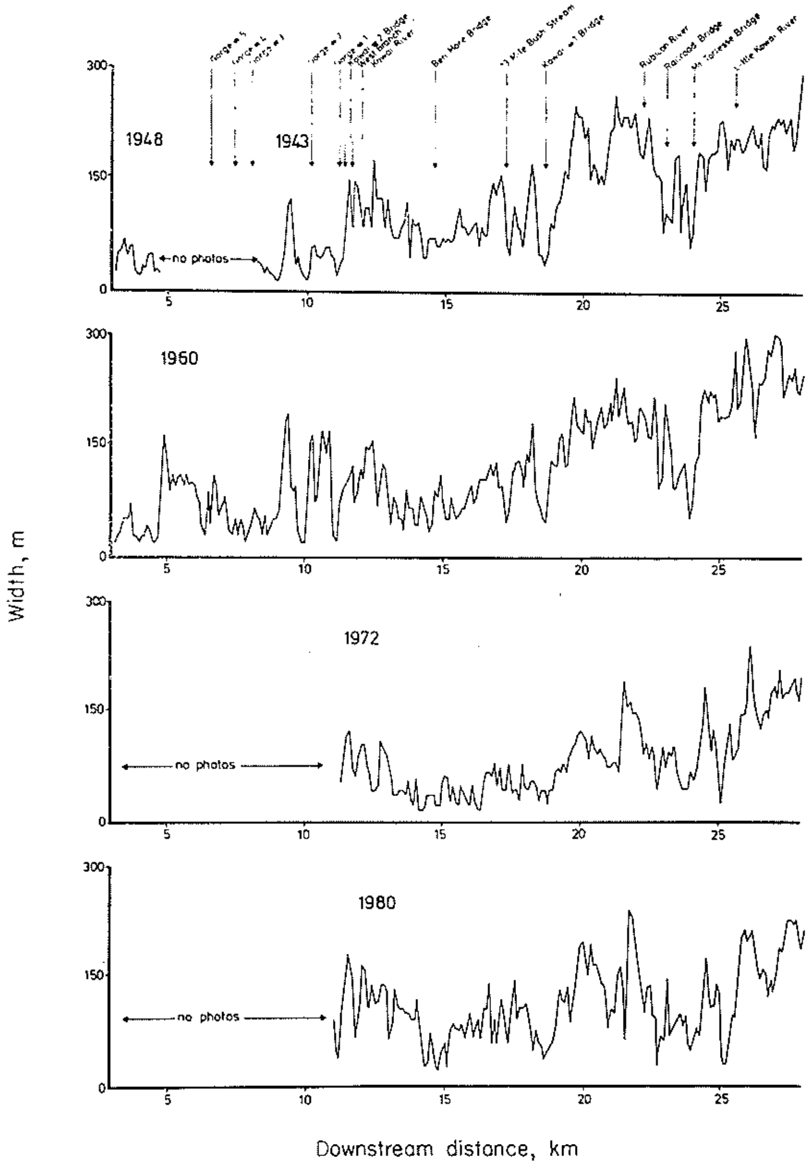

FIG. 2—Channel widths of the Kowai River (distánces correspond with Fig. 1).

the Kowai River, especially between the 5 and 11 km distances, and associated tributaries of the upper basin. Pronounced or systematic changes in width generally did not occur downstream of the 11 km channel location.

The relatively narrow portions of the Kowai River (Fig. 2) are almost invariably associated with bridges and bedrock gorges. Channels in gorges are unable to widen significantly during high flow, even during periods of extensive aggradation. Highway and railroad bridge abutments and embankments may similarly constrain channel widths. It is not known whether the bridges were located at naturally occurring narrow sections of the Kowai River, or whether the channel was narrowed by construction alone.

Assuming the depth of scour is not physically limited by bedrock or by alluvium so coarse as to be immobile, maximum changes in bed elevations would probably occur during high flow in these constrained channel reaches. The bed would normally scour deeply and then refill during receding flood flows (Lane and Borland, 1953). Immediately upstream of the constrained reaches, the impounding effects of bridges and gorges may accentuate the aggradation from increased sediment supplies, and delay the routing of sediment downstream. Reaches that are alternately constrained and unconstrained by channel banks may operate as a series of reservoirs through which bed material is routed. The ability of each reservoir to delay sediment would depend upon a host of variables; the original dimensions and morphology of potential storage locations, the amount of sediment in storage, the rate of sediment influx and the streamflow regime, and the characteristics of the constricted channel. Additional factors affecting channel aggradation in major rivers of southern Oregon and northern California, USA, are identified by Lisle (1981), including the spatial distribution of erosional processes supplying sediment, the dispersion and sorting of sediment transported downstream, and the delay of an aggradation sequence propagated downstream in arriving at a particular reach.

In order to help distinguish temporal changes in channel width from background variability, the Kowai River channel was divided into relatively homogeneous reaches between distances of 8 and 28 km. Tributary junctions, gorges, and bridges were used as a basis for subdivision; channel widths measured at those locations were excluded from analysis. In 1943 the trend in average channel width for these reaches increased progressively, although somewhat irregularly, in a downstream direction (Fig. 3a). The 1943 photographs reveal that tributaries flowing into the Kowai River had a variable influence on active channel widths (Fig. 3a); downstream of tributary junctions, the channel was sometimes wider and sometimes narrower than upstream.

Paired t-tests (Lyons and Beschta, 1983) were used to evaluate changes in channel width that occurred during the periods 1943-60, 1960-72, and 1972-80 (Fig. 3b). Channel changes were expressed in percent of channel width measured at the beginning of each period. For the 1943-60 period, highly significant ($\alpha=0.01$) increases in channel width occurred between

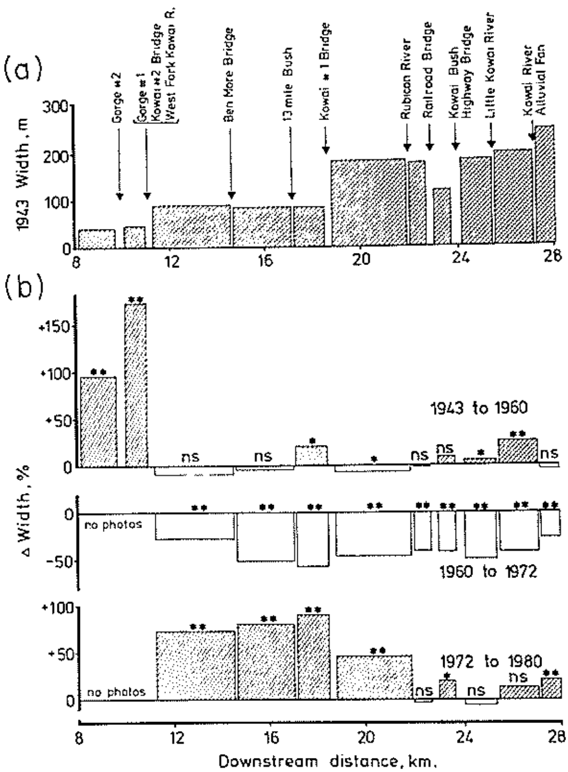

FIG. 3—(a) Average channel widths for selected reaches of the Kowai River in 1943 and (b) changes in width during the indicated periods. NS = non-significant, * = significant at α =0.10 and ** = highly significant at α = 0.01.

the channel distances of 8 and 11 km. The largest increase was in the reach directly upstream of the Gorge No. 1 and Kowai No. 2 Bridge, where extensive aggradation and widening resulted from a flood in 1951. Immediately downstream of these constrictions width decreased slightly, even though this section also experienced high flows from the 1951 flood. Why such a difference in channel response by two adjacent reaches? If width responds primarily to high flow, similar width changes should have resulted; but they did not. The lack of channel widening in the downstream reach thus indicates that the total volume of bedload transported through the gorge was sufficiently low that aggradation did not occur. Therefore, relatively high sediment loads had a larger impact on long-term channel widening than the high streamflow.

Statistically significant (α=0.10) increases in width occurred below the confluence of the 13 Mile Bush Stream for the period 1943-60. Immediately upstream of the confluence, bank erosion of glacial deposits along the Kowai River channel removed over 60,000 m^3 of coarse sediment between 1943 and 1975 (P. Ackroyd, personal communication, Centre for Resource Management, Lincoln College, Canterbury). Comparison of aerial photographs indicated that much of this bank erosion occurred prior to 1960 from a 9.4 m high terrace. The widening of the channel downstream of 13 Mile Bush Stream may reflect this local influx of sediment.

The Kowai River widened significantly below its confluence with the Little Kowai River during the period 1943-60. Hlllslope and channel erosion increased sediment supplies of that tributary system during the 1951 flood. Bed material exported from the Little Kowai River probably caused the widening of the Kowai below their confluence. Similarly, Lyons and Beschta (1983) found that high sediment yields from tributaries caused localized widening of the Willamette River in western Oregon, USA. For the years 1943-60, only minor changes in width were found for sections of the Kowai River downstream of the West Branch of the Kowai River and the Rubicon River confluence (Fig 3b). These rivers were relatively unaffected by the 1951 storm, primarily because hillslope failures were infrequent in these basins.

From 1960 to 1972, highly significant reductions in channel width, averaging approximately 50 percent, occurred along the Kowai River as vegetation encroached on portions of the 1960 active channel. Although streamflow records are not available for the Kowai River, precipitation measured at Mt. Torlesse Station indicate a lack of major storms during the period. The smaller-than-average reduction in width between channel distances of 11.4 and 14.6 km may indicate that sediment was moving into this reach from upstream. Because sediment stored upstream of the bridge was being scoured and reworked by the Kowai River (Beschta, 1983, the next downstream reach should be first to show widening, or more specifically, a lack of narrowing.

The 1972-80 period comparisons (Fig. 3b) show a highly significant widening, generally in excess of 50 percent for 11 km downstream of the Kowai No. 2 Bridge (11.2 km). Part of the increased width shown for the two sections between the 13 Mile Bush Stream (16.2 km) and the Rubicon River (21.9 km) tributary junctions could be attributed to downstream transport of sediments from the eroding 9.4 m-high glacial terrace upstream of the 13 Mile Bush Stream confluence. Reaches farther downstream show relatively small changes in channel width. Thus, sediment stored in upstream channels during the April 1951 storm was affecting channel widths along the middle reaches of the Kowai River in 1980.

The dimensions of stream meanders for nonbraided channels have long been known to be strongly influenced by flow volumes (Friedkin, 1945). Although the Kowai River is braided, the possibility exists that braided streams may also exhibit characteristics that have a periodic component (Thornes, 1976). Since active channel widths were measured at equally spaced intervals along the channel, autocorrelation analysis could be

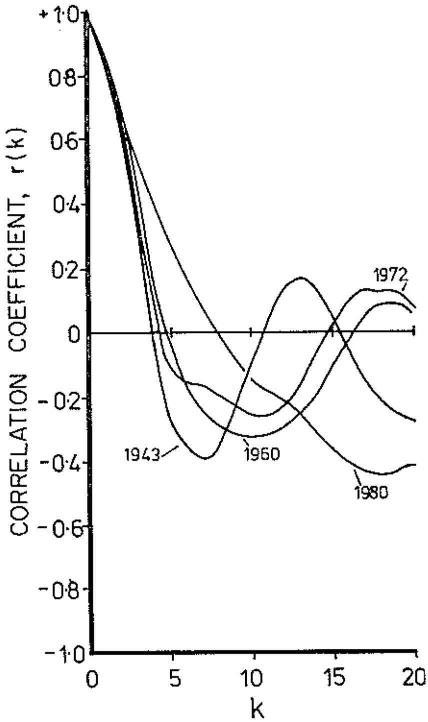

FIG. 4—Correlograms of 5-point moving averages of detrended channel widths. Each lag k represents 0.1 km of channel distance.

undertaken to test this hypothesis. Although widths for the lower 17 km of the Kowai River were available (Fig. 3), analytical constraints limited use to only a portion of this data. Leopold and Wolman (1957) indicate an exponential relationship between flow and wavelength. If channel widths behave similarly, the wavelength associated with any channel characteristic having a periodic component would increase with distance downstream as drainage area and streamflow increased. Thus, autocorrelation analysis (Kendall, 1976) over the entire 17 km reach would provide an inaccurate indication of channel width periodicity. In addition, naturally occurring gorges and man-made structures influence channel widths and cause them to appear spatially nonstationary. To minimize the effect of these factors, the reach located between channel distances 11.4 and 18.3 km was chosen for analysis. Although the Ben More Bridge occurs in this 7 km reach, it is not a major structure and did not appear to have a significant effect on the width characteristics of the Kowai River in 1943.

Correlograms of channel widths (Fig. 4), based on the 1943, 1960, 1972 and 1980 aerial photographs, indicated a substantive trend in channel width. This non-linear trend, accounting for channel width variation of 25 to 50 percent with downstream distance, was removed from the data. The correlograms were developed from 5-point moving averages of the detrended channel width residuals. The 1943 correlogram suggests a cyclic component in active channel widths with a wavelength of approximately 1.3 km. Active channel widths in 1960 and 1972 also show cyclic components; however, the wavelength increased to approximately 1.8 km. These wavelengths indicate that narrow and wide active channels recur at a spacing of 15 to 35 times the average width. These wavelengths are greater than those typically associated with meanders and also nearly an order of magnitude greater than those generally found for pool-riffle spacing in single-thread channels. However, in semi-arid channels, Thornes (1976) has identified oscillatory variation in channel widths at several wavelengths; the largest oscillations tending to decrease in wavelength as channel width increased. His data are for relatively narrow channels (i.e. 2-30 m) in comparison to the active channel width of the Kowai River, but indicate that the relatively large oscillations have wavelengths of approximately 10 to 30 times the average channel width.

From 1972 to 1980, aggradation and substantial increases in channel width obliterated any periodic or harmonic characteristics of the reach between 11.4 and 18.3 km. By 1980, the periodic component had largely disappeared or greatly increased in wavelength. Relatively constant negative correlation coefficients at higher lags indicate the presence of nonstationarity in a data set (Rao, 1980) and apparently occurred with the 1980 channel widths (Fig. 4); relatively small increases in width occurred at the Ben More Bridge and immediately downstream as the channel aggraded. Active channel widths in the vicinity of the bridge in 1980 averaged less than one-third of those farther upstream or downstream.

SUMMARY AND CONCLUSIONS

Changes in active channel width of the Kowai River for the period 1943 to 1980 suggest the downstream progression of a major wave of bed material sediment. This "wave" was initiated during the 1951 storm as a result of storm-induced hillslope erosion in the upper reaches of the Kowai River Basin. In 1960, the leading edge of this wave was located at a channel distance of about 11.5 km from the basin divide. As of 1980, this wave of sediment had moved an additional 11 km downstream and was only 6 km from the Waimakariri River confluence. Thus, the leading edge was being translated at an average rate of several kilometers per decade; an indication that considerable lag times occurred between the increase in sediment availability and the resultant downstream channel responses. Even longer lag times might be expected before active channel widths return to those present prior to the major influx of sediment. Large volumes of sediment made available during the 1951 storm still remain 30 years later in the upper reaches of the Kowai River and its tributaries.

Man-made structures, such as bridges, are generally associated with narrow channel widths. The same is true for naturally resistant banks, particularly gorges. These structural controls slow the downstream progression of sediment by impounding material upstream. The greatest increases in channel widths were found immediately upstream of the Kowai No. 2 Bridge and the Kowai No. 1 Bridge in 1960 and 1980, respectively; thus much sediment was deposited in response to local channel constrictions.

Although the Kowai River is braided throughout most of its reach, a periodic component in active channel widths was identified; however, it disappeared as the active channel significantly widened between 1972 and 1980. Relative change in the active channel widths of braided streams can be used as a surrogate variable for indexing aggradation where channel widths are not constrained by bedrock, man-made structures, resistant banks, and so on. During high flows in the Kowai River, changes in active channel widths were influenced more by sediment loads than by water discharge. Where vegetation removal during high flows provides an easily measurable signature of active channel widths on aerial photographs, the tracking of downstream migration of depositional zones is facilitated. Because of the large number of factors affecting channel morphology, active channel widths can be used only as a qualitative indicator of response direction; not a quantitative indicator of bed material volumes. Results indicate that the concepts of complex response proposed by Schumm (1971, 1973, 1977) are applicable to the Kowai River basin, where an episodic increase in sediment supply occurred in 1951. Finally, these results suggest that relative bed material loads might be an important source of variability affecting hydraulic geometry relationships (Griffiths, 1980a) for many of New Zealand's gravel bed rivers.

ACKNOWLEDGEMENTS

The author wishes to thank the Centre for Resource Management, Lincoln College, for providing financial assistance during this study while the author was on sabbatical leave from Oregon State University, USA.

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