WATER & SOIL
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RECORDED CHANNEL CHANGES OF THE UPPER WAIPAWA RIVER RUAHINE RANGE NEW ZEALAND

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by
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ABSTRACT

Changes of active bed width (ABW), mean bed level (MBL) and channel slope since 1920 have been estimated at numerous sites on the upper Waipawa River. Records were based largely on field measurements, vertical aerial photographs and oblique ground photographs.

Dominant trends during the recorded period were increasing ABW, rising MBL, steepening of channel slope and an increase in the size and frequency of occurrence of riparian landslides on greywacke.

At Waipawa Fork, from 1961 to 1975, North Branch MBL rose 8m and South Branch MBL rose 7m. From 1950 to 1975 the confluence of the two branches receded 117m up stream, and nearby reach ABWs increased up to 113%.

On McCullough's mill reach, 583m long, the reach MBL rose 1.1m from 1960 to 1975. From 1950 to 1975 the reach ABW increased 43m or 146%, the channel slope increased from 0.033 to 0.036 and the channel sinuosity index declined from 1.07 to 1.00.

Along lower reaches rise of MBLs has been general, and between 1950 and 1975 average increase of ABW for a channel length of 6.9km was 63%.

Recorded channel morphology trends have resulted from increase in sediment transport rates. There was a major burst of sediment transport activity in the mid 1930s followed by a relatively tranquil period. A year or two before 1949 marked the onset of a phase of progressively increasing activity which persisted to 1976 at least. The average sediment transport rate is now (1970s) about 3 times that of the 1960s, 6 times that of the 1950s. and 13 times that of the early to mid 1940s.

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CONTENTS

INTRODUCTION

Throughout the Ruahine Range the current trend of change appears to be one of accelerated denudation, erosion and bed load transport rates. This is producing numerous downstream practical problems which concern water resources, flood control, public access ways and private property. However rate of change varies from basin to basin.

Greater understanding is needed of environmental changes and processes and cause-effect relations. This report on the Waipawa River basin records available knowledge on channel changes and an attempt is made to define the gross pattern of change in time. Processes of change and cause-effect relations are to be dealt with in a later paper.

UPPER WAIPAWA BASIN

The Waipawa River is on the eastern side of the Ruahine Range divide and is a major tributary of the Tukituki River which flows into Hawke Bay on the east coast of the North Island (Fig. 1). This study concerns only the upper Waipawa River, viz, that portion up stream of its confluence with the Makaroro River. The drainage area of 125km^2 comprises the four major basins: Mangataura, Upper Waipawa proper, Middle and Smith (Fig. 2). The Upper Waipawa proper is considered, with some supplementary information from the three tributaries.

Altitudes rise from about 610m at the toe of the range to 1703m at the divide. Most of the rainfall comes from westerly quarters but periodically the region is subjected to cyclonic storms which usually come from north-to-east. Average annual precipitation is 1300mm at the Waipawa-Makaroro confluence, 2800mm at the toe of the range near Waipawa River, and around 5000mm near the divide. Above 1100m altitude snowfall probably contributes 5–10% of total annual precipitation.

The Ruahine Range is composed chiefly of interbedded Triassic-Jurassic greywackes and argillites (Kingma, 1962) which are complexly folded and faulted and which as a consequence are very shattered. These rocks constitute the source for channel bed material. To the east the rocks, which are mainly siltstones, with some sandstones and coquina limestones, are of Pliocene and Pleistocene ages. Major faultlines, rock types and current source areas for bed material are approximately shown on Fig. 3.

Preliminary mapping of eroded surfaces of the entire upper Tukituki Basin was carried out in 1974 by N.Z. Forest Service staff using aerial photographs of 1966 (Survey No 1698). In the upper Waipawa Basin mapped eroded areas on greywacke, by sub-basin, were: Mangataura, 0.37km^2; upper Waipawa proper, 2.46km^2; Middle, 1.02km^2; Smith 1.66km^2.

Fine textured soils vary greatly in thickness and are widely absent owing to erosion.

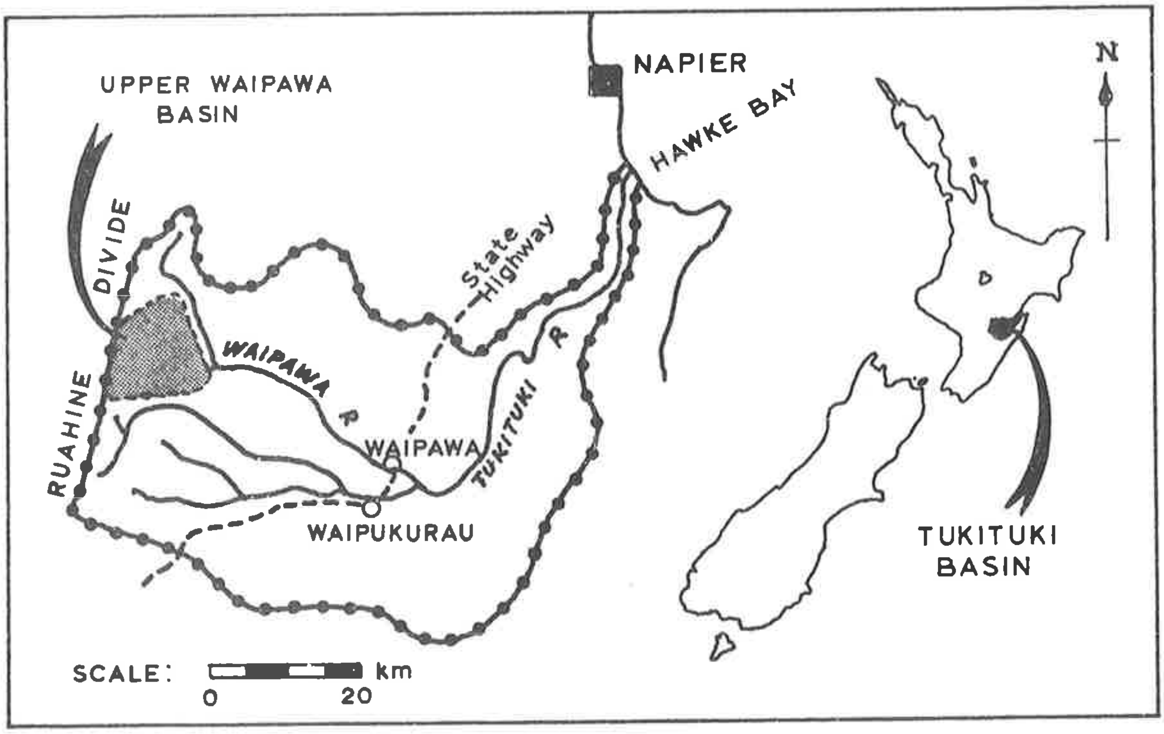


FIG 1 – Locations of the Tukituki and upper Waipawa basins, North Island New Zealand.

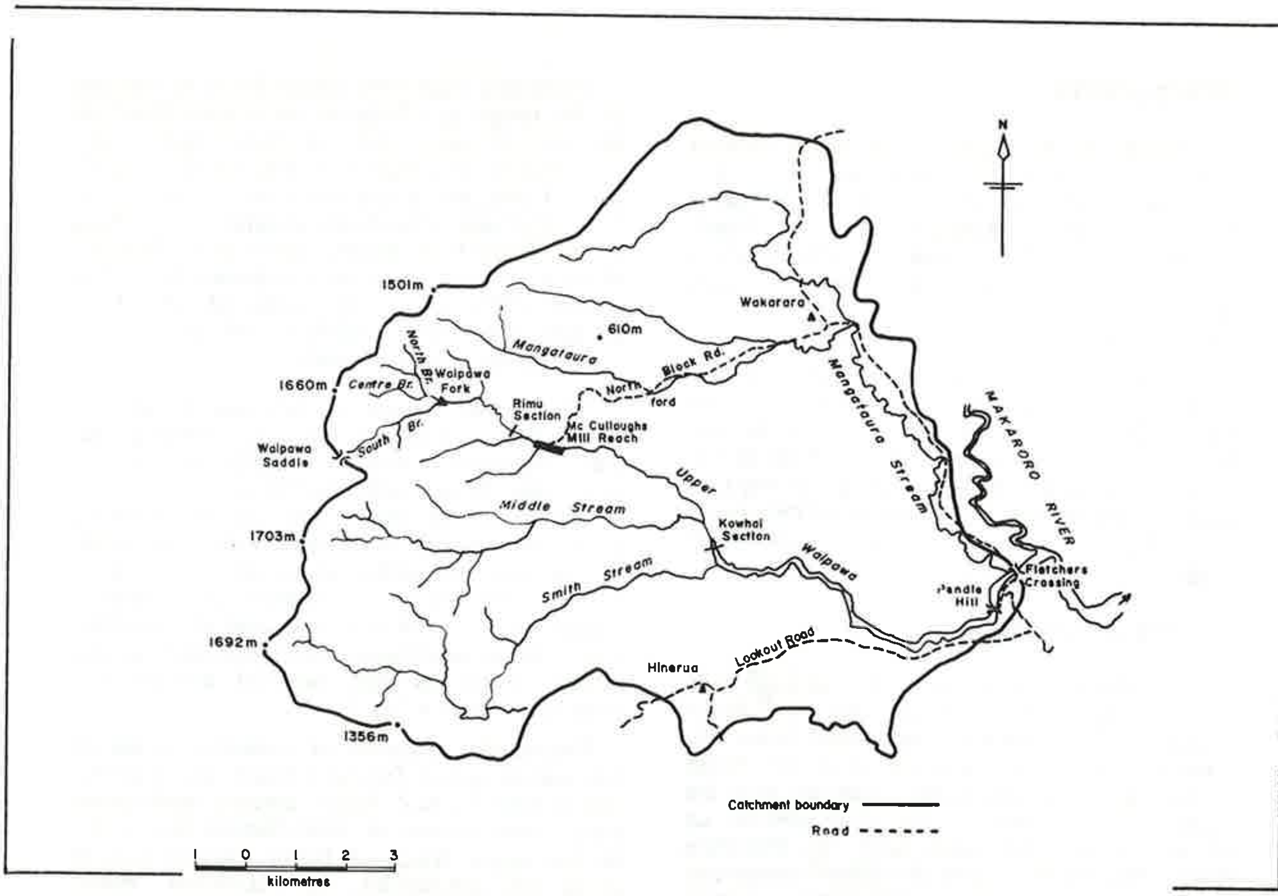


FIG 2 – Upper Waipawa Basin drainage tributaries, access, and study sites.

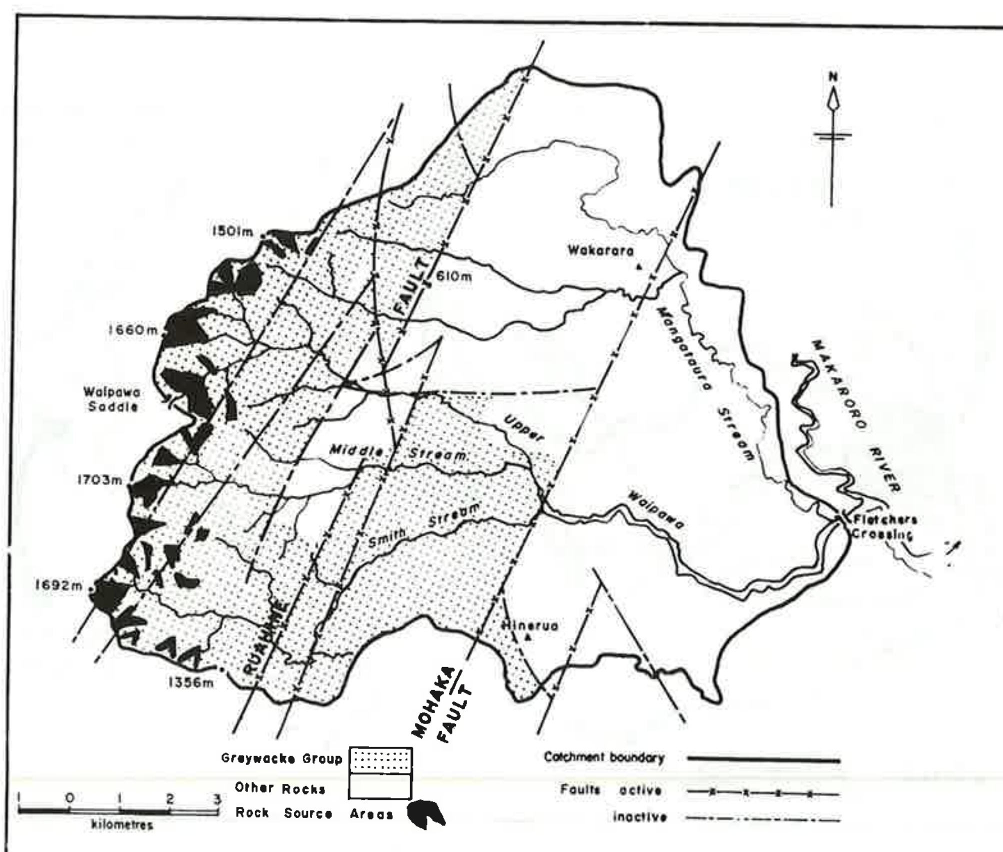


FIG 3 – Major rock types and faults (after Kingma 1962), and approximate rock source areas of the upper Waipawa Basin.

Several allophane tests (Fieldes and Perrott, 1966) by the writer on fine soils about 1550m altitude have given strong positive reactions which indicate a high probability that the fine textured soils consist entirely or largely of volcanic ash. No detailed soil studies have been undertaken in the region.

The vegetation of the rangeland grades erratically upward from red beech *(Nothofagus fusca)* – rimu *(Dacrydium cupressinum)* dominant forest, through red-mountain beech *(N. solandri var cliffortioides)* forest, to mountain beech which dominates to a treeline around 1220–1370m. Where vegetation exists above the treeline it is usually either grassland dominated by snowgrass *(Chionochloa rigida)* or shrubland dominated by leatherwood *(Olearia colensoi)*.

Probably during the 1910s red deer entered the region; opossums have been there since about the 1920s (Elder, 1965; N.Z. Forest Service, 1966).

Fig. 4 shows longitudinal channel profiles, derived from the NZMS 1 map series and field checks and notes average channel slopes and locations of study sites.

Maximum bed material sizes (rolling diameters) in 1974 were: 0.55m at Fletcher's Crossing, 1.7m on McCullough's mill reach and 2.4m at Waipawa Fork.

At Fletcher's Crossing, with a drainage area of 125km^2, an extreme low flow of 899 l/s was measured on 5 February 1973 (Grant, 1973); and on 12 March 1975 a major peak discharge of 370m^3/s was determined from flow measurements.

CHANNEL MORPHOLOGY

Channel morphology measurement was largely based on profiles measured on cross-sections which traverse the river bed from bank to bank and which are aligned approximately normal to the river reach. Each section was marked and suitable level reference points were established. For each reach a level datum was assumed. Distance and level values were rounded appropriate to both methodology and channel circumstances.

The mean bed level (MBL) of the active bed width at the time of measurement (ABW being the channel width applicable to bed material transport) was calculated for each profile using the definition:

$$MBL = \left(\sum_{i=1}^{n} d_i \, l_i \right) / (ABW)$$

where d is distance interval between point levels

l is mean level for a distance interval.

At section sets, channel slope was calculated from section MBLs; elsewhere it was measured in the field.

Aerial photographs used to supplement field measurements were taken and produced by N.Z. Aerial Mapping Ltd.for the Department of Lands and Survey.

McCULLOUGH'S MILL REACH

About 1934 J A McCullough established a timber mill on a large forested alluvial flat on the left bank of the upper Waipawa River (Figs. 2, 5).

Reach Changes Since 1950

The writer established channel cross-sections A to C in 1955 and sections D to F in 1960 (Fig. 5). Measured values of ABW and MBL are given in Appendix 1.

Interpretation of ABW changes should be made in the context of the total width available, or potential ABW. Potential ABWs were measured on the ground and relations with ABW values of September 1975 are given in Table 1. Although sections E and F have attained their potential ABW small increases may result from either bank erosion or rise of MBL.

TABLE 1: Relations between potential ABW and ABW at September 1975 for each section on McCullough's mill reach.

Section	a Sep 1975 ABW(m)	b Potential ABW(m)	a/b x 100
A	56.0	82.3	68.0
B	78.6	125.3	62.7
C	105.2	111.9	94.0
D	57.0	71.0	80.3
E	39.4	39.4	100
F	30.2	30.2	100
	366.4	460.1	mean: 79.6

With some fluctuation ABW has progressively increased and MBL has risen on every section. At times lower, not higher, MBLs have accompanied increased ABWs. This suggests, where potential ABW has not been reached, that in the short term ABW is a more sensitive indicator of relative bed load transport than is MBL.

Changes of MBL at any one section are subject to high random space and time variability which makes one section an unreliable indicator of change during relatively short periods. Therefore it is desirable to have a more stable index of change. This may be obtained from the reach – mean values of a channel where a set of closely spaced sections exists (Appendices 2, 3). Periodic annual

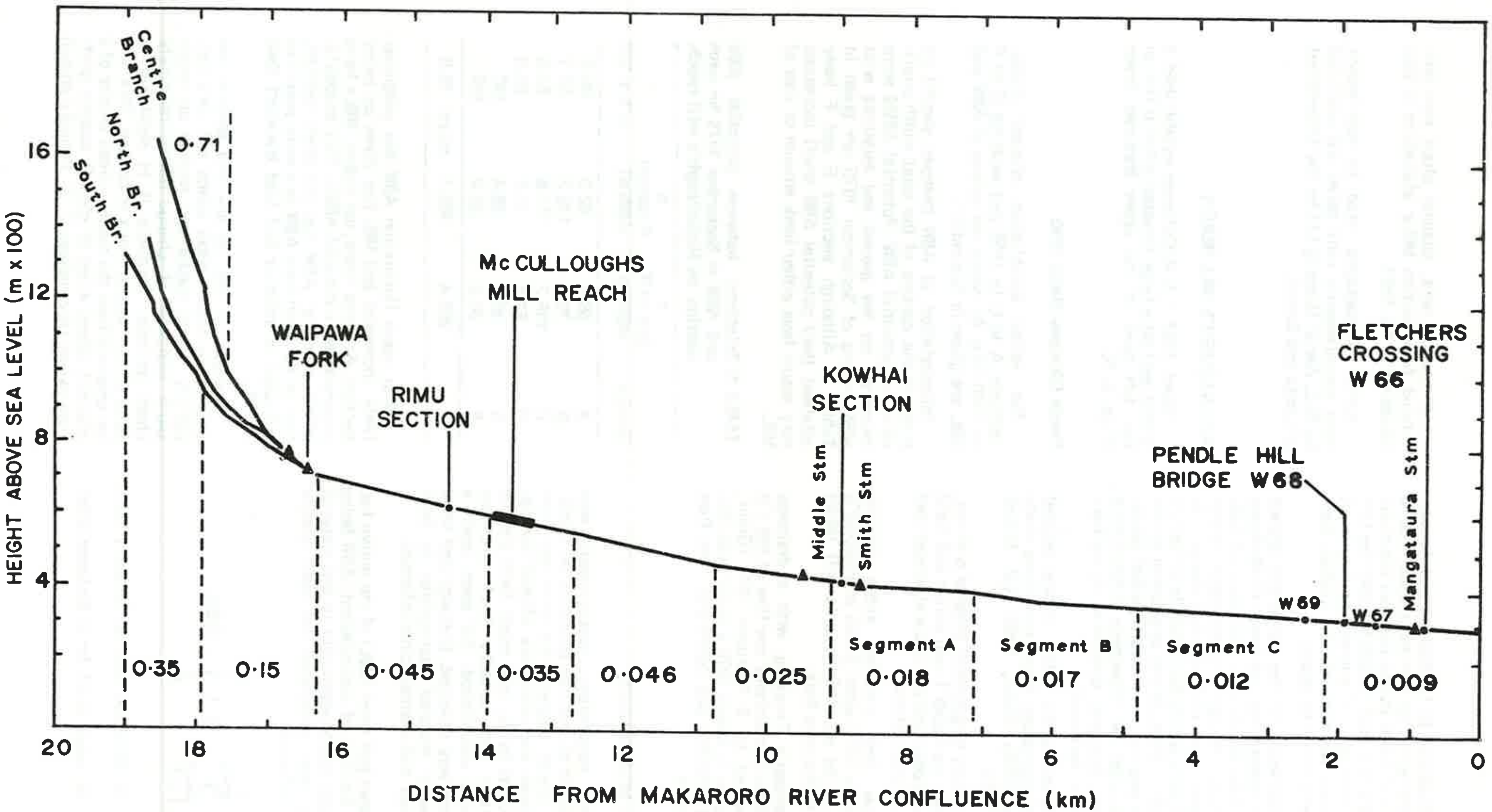
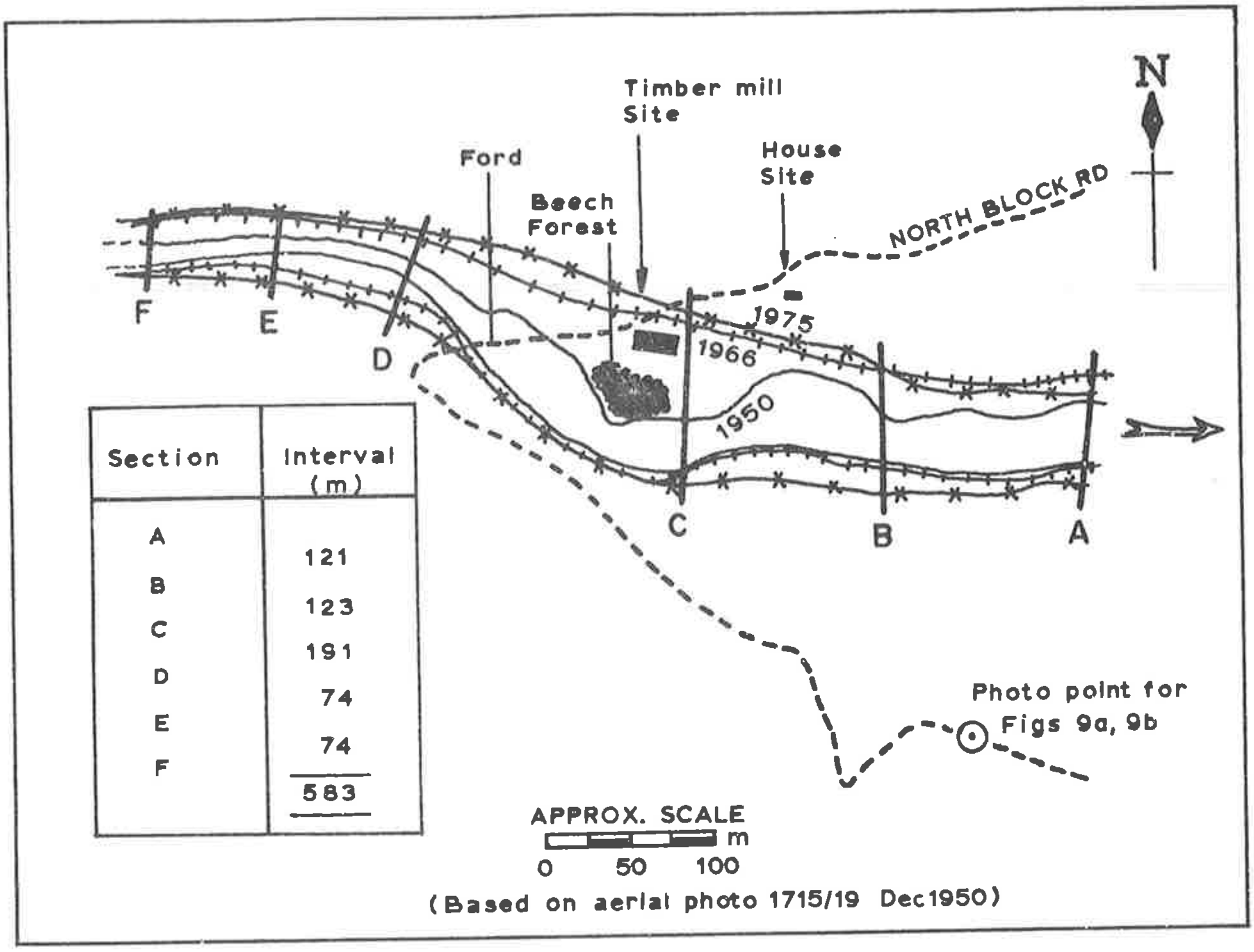


FIG 4 – Channel longitudinal profile of the upper Waipawa River. Approximate average slope values are shown.



Section	Interval (m)
A	
	121
B	
	123
C	
	191
D	
	74
E	
	74
F	
	583

FIG 5 – Cross-sections, and active bed limits for 1950, 1966 and 1975, on McCullough's mill reach. Section intervals are for 1975.

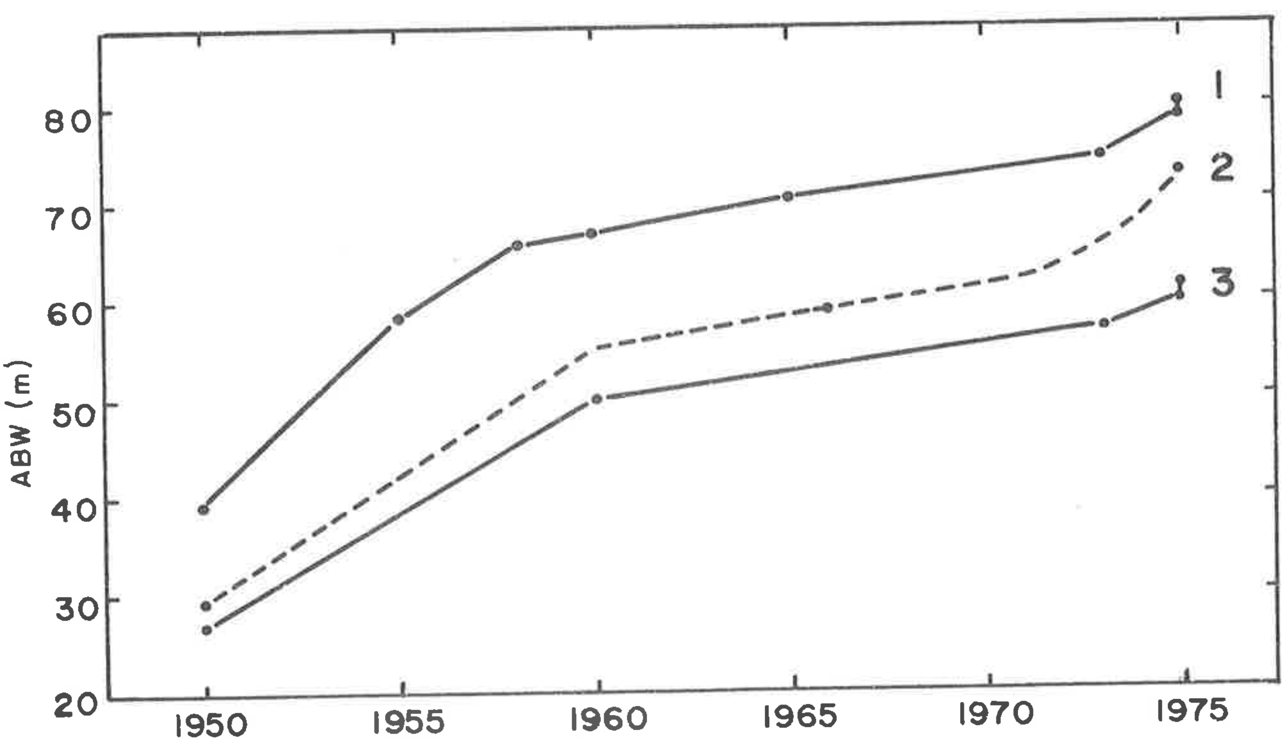


FIG 6 – Changes of average ABW on McCullough's mill reach based on : 1. sections A–C, 2. aerial photos, 3. sections A–F.

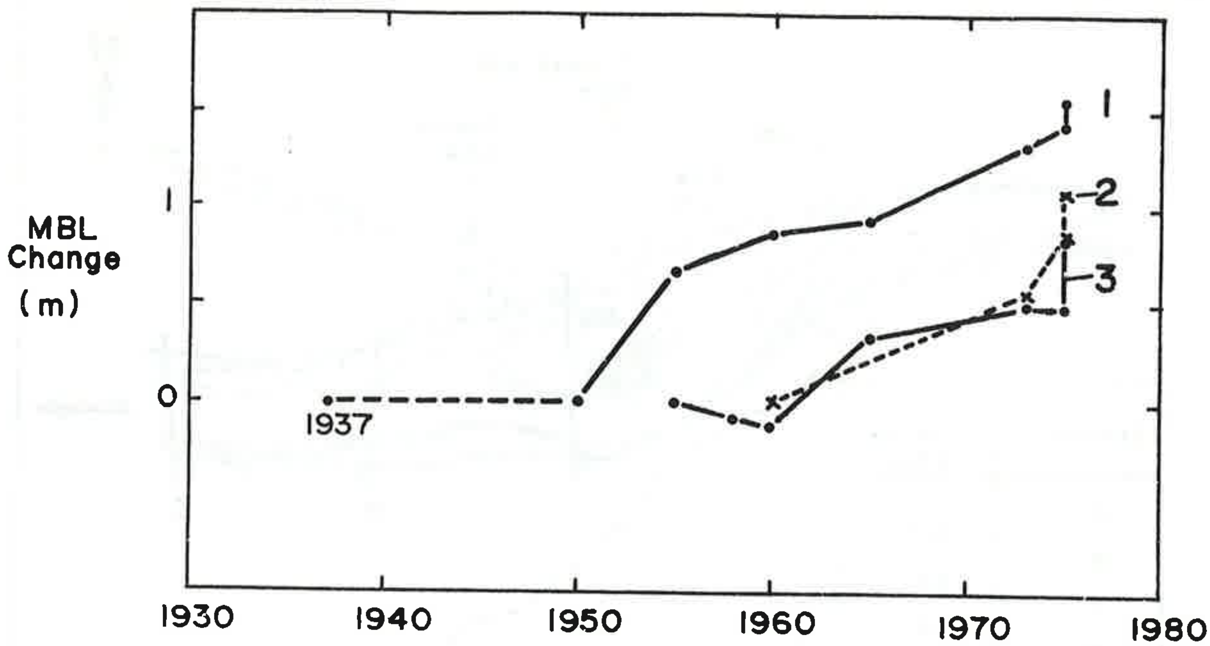


FIG 7 – Cumulative changes of MBL on McCullough's mill reach for : 1. section C, 2. sections A–F, 3. sections A–C.

average values of MBL change are also given; however, because the processes of change operate intermittently these values are not real, but they are useful comparative indices.

Fig. 5 shows the edges of the active bed taken from aerial photographs of 1950, 1966 and 1975. For each date the area of active bed between sections A and F was determined and average width was calculated (Appendix 4). Patterns of ABW and MBL changes are shown in Figs. 6 and 7.

Widening of the reach has been accompanied by reduction of channel length which may be expressed by the sinuosity index: ratio of channel length to valley length. If at September 1975 the sinuosity index is taken as 1.00 then at December 1950 it was 1.07.

Assuming that the A–F channel fall was about the same in 1950 as in 1960, then the channel mean slope in 1950 would have been .033 (m/m). By adopting this value, the reach A–F mean slopes from 1950 up until September 1975 (Fig. 8) show a persistent trend of channel steepening.

Some Changes Since 1920

Figure 9a was photographed in 1937; Fig. 9b was taken in 1976. Scaling, controlled by ground measurements, on both Fig. 9a and 1950 aerial photos permitted approximate reconstruction of the profiles on section C in 1937 and 1950. Changes of MBL at section C (Appendix 5) are shown on Fig. 7.

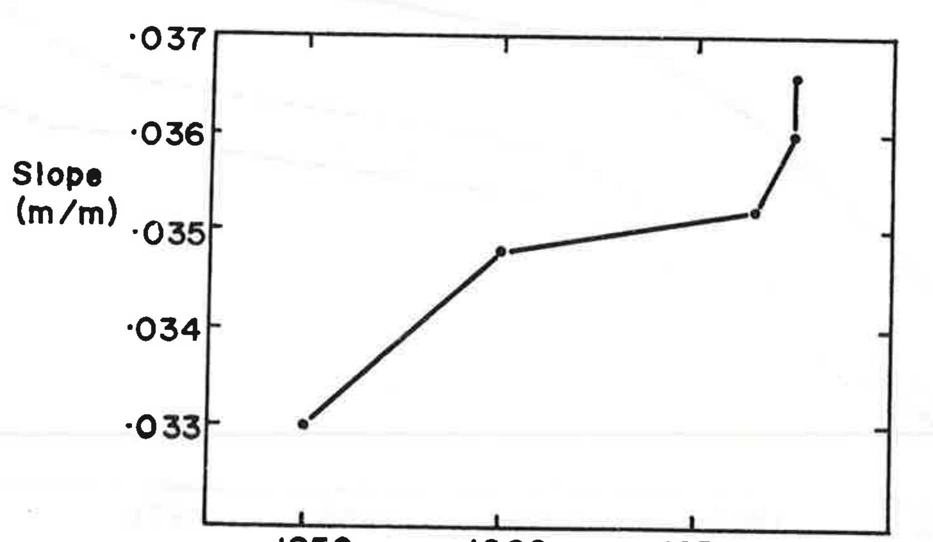


FIG 8 – Changes of mean channel slope on McCullough's mill reach.

FIG 9a – McCullough's timber mill and house at the left bank of the upper Waipawa River in 1937. The mill building site was at least 3m above the adjoining river bed. Compare with Fig 9b. Photo: Mrs W H Macdonald, Wakarara.

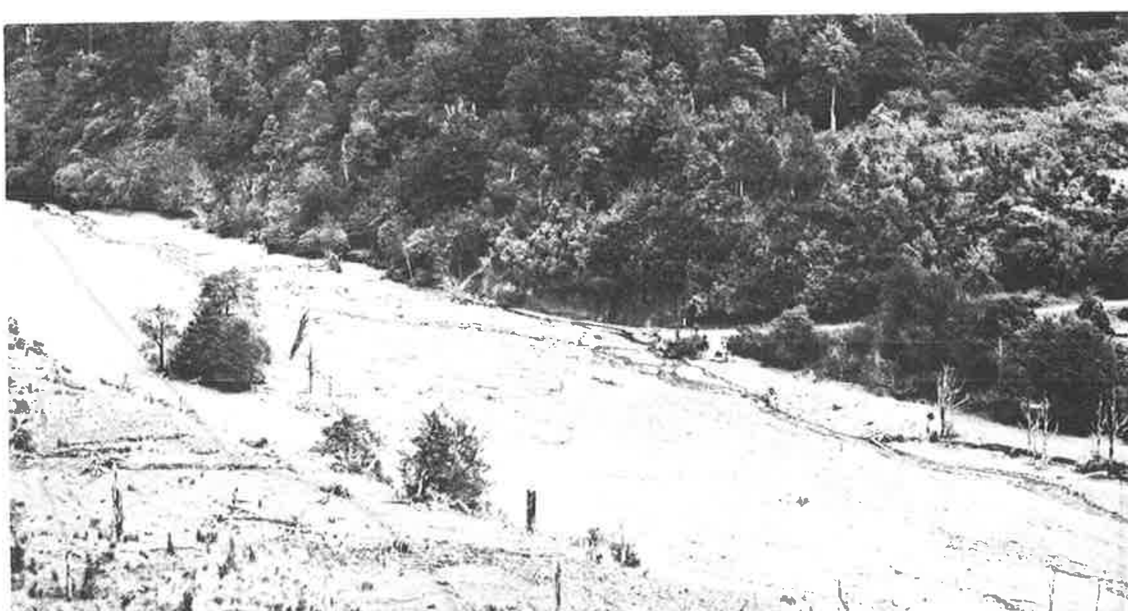


FIG 9b – Locations of McCullough's timber mill and house in 1976. The channel has aggraded, widened, straightened and steepened and the mill site is now river bed.

From Messrs H Baker, A A Hutt and H Worsnop of Ongaonga and Mr S Bridge, Argyll East, it was ascertained (pers. comm.) that from about 1920 to the early 1930s the river channel at the mill site was no more than 20m wide. Fig. 9a shows that ABW expansion had taken place a short time before 1937. This was confirmed by finding, along the channel margin down stream of section A, stands of kanuka *(Leptospermum ericoides)* which established in the mid 1930s (by growth ring counts) on coarse alluvium. The pattern of ABW change at section C is shown in Fig. 10. It is reasonable to assume that the section C patterns of ABW and MBL change before 1950 qualitatively apply to the channel reach.

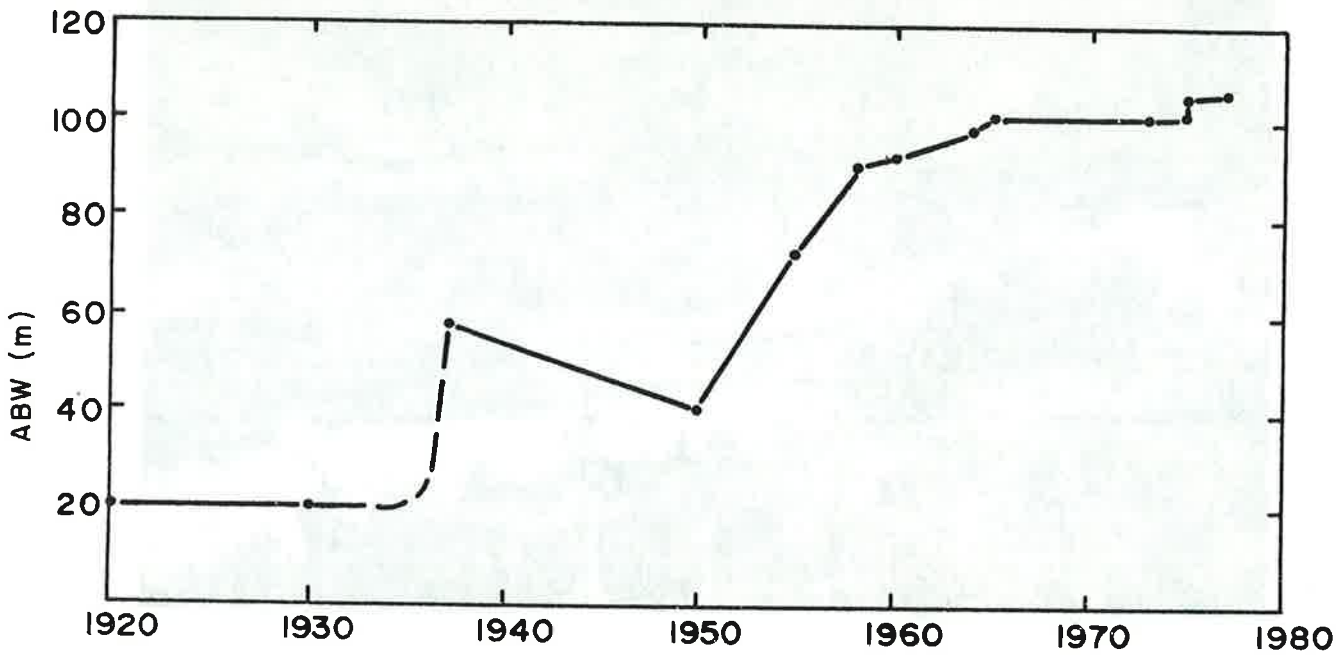


FIG 10 – Changes of ABW at section C on McCullough's mill reach.

The amount of fresh alluvium deposited at a section is best expressed by change of cross-sectional area (CSA). The overall pattern (Fig. 11) indicates that a marked acceleration of bed load transport took place up stream of and through McCullough's mill reach about, and probably a little before, 1950.

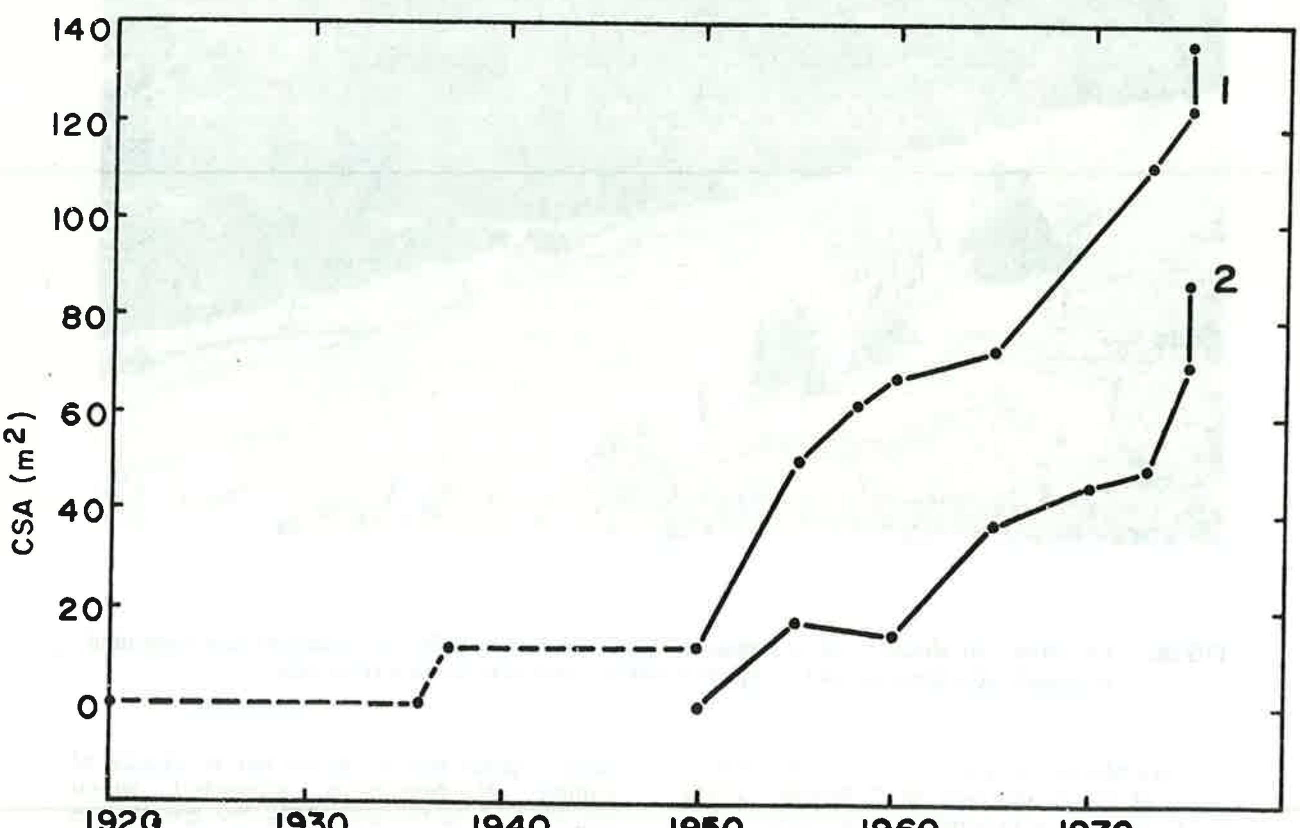
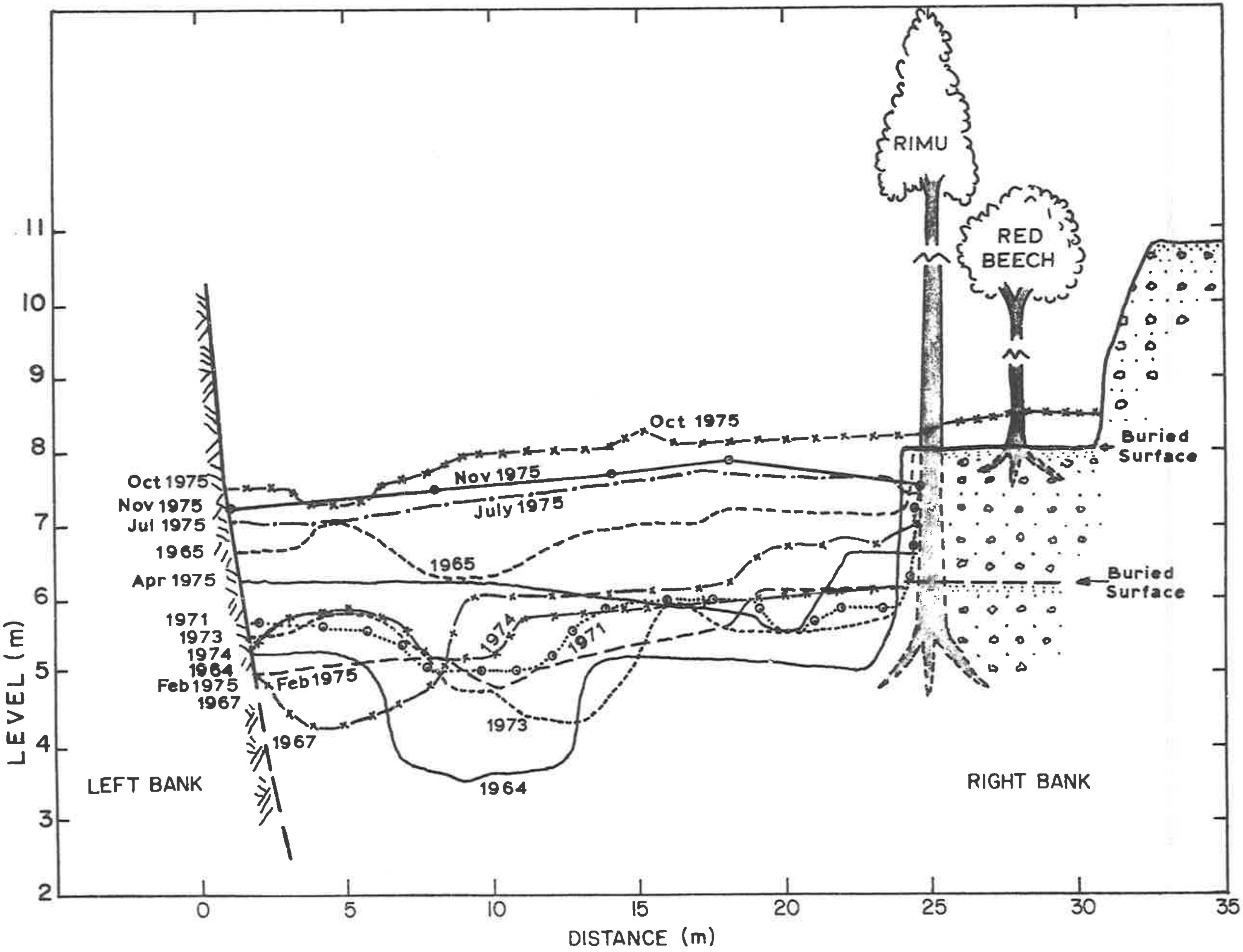


FIG 11 – Cumulative decreases of channel cross-sectional area (CSA) resulting from deposition of alluvium on McCullough's mill reach for: 1. section C, 2. average of sections A–C (1955–60) and A–F (1960–75).

FIG 12 – Channel profiles at the rimu section.



RIMU SECTION

Figure 12 presents a set of 11 channel profiles measured at the rimu section since December 1964. MBL values and periodic average annual rates of change are given in Appendix 6.

From December 1964 to November 1975 MBL fluctuated markedly but resulted in a net rise of 2.9m. Average rates and directions of change indicate that aggradation was most persistent during 1975. However, it seems that the rate of aggradation, for a short period, was greatest during December 1964 – April 1965. By October 1975 aggradation had resulted in the deposition of alluvium on the old vegetated surface behind the rimu.

Channel slope through the rimu section was 0.045 in October 1973 and 0.049 in October 1975 – a steepening of 4m/km. This trend is the same as at McCullough's mill reach but is more pronounced.

Between McCullough's mill reach and the rimu section observations at channel edges clearly indicate that a general rise of MBLs, coupled with ABW widening, has occurred in recent years. Although the changes recorded at the rimu section cannot be quantitatively transferred to a reach they are large enough to leave no doubt that qualitatively they reliably demonstrate the trends of channel change up stream from McCullough's mill reach.

WAIPAWA FORK

Waipawa Fork which is the confluence of the North and South branches of the upper Waipawa River (Figs. 2, 4) has a total drainage area of 5.2km^2. The point of confluence has been taken as the limit of vegetation at its downstream apex between the two branch channels. Aerial photographs of 1950 show that the vegetation apex had already been breached by the steeper North Branch resulting in an island of vegetation. In December 1961 the surface of the island was several metres above the active bed, beech trees at least 60 years old had been felled by Forest Service staff and the site used as a helicopter landing pad. Since then changes have been drastic. The confluence has receded up stream as a result of lateral erosion and vegetation drowning by bed material transported down the steeper North Branch (Fig. 13). Table 2 shows that between the 1890s (from tree age) and 1950 the recession was at least 43m, and from 1950 to 1975 it was 117m.

FIG 13 – Waipawa Fork, 1976 – the confluence of South Branch at the left and the steeper North Branch entering from the right. The fork section (Fig 14) lies approximately across the middle of the figure.

TABLE 2 : Upstream recession of the confluence of North and South branches at Waipawa Fork.

Date	Relative Upstream Position(m)	Rate of Change (m/y)	Description	Aerial Photo Reference
c. 1890s	0		Downstream limit of vegetation island	1715/17, Dec 1950
		<0.7		
Dec 1950	43		Vegetation apex, island about 15m long	1715/17, Dec 1950
		0.94		
Dec 1966	58		Vegetation apex, island gone	3910/29, Dec 1966
		11.33		
May 1975	160		Vegetation apex	C/20, survey 2800, Feb 1975 C/22, survey 2846 May 1975

For comparable channel reaches the average channel slope of North Branch increased from 0.15 in 1965 to 0.18 in 1976; South Branch increased from 0.11 to 0.13.

Channel cross-profiles, approximately through the old Forest Service camp site, were reconstructed for 1961 and 1965 using photographs taken by the writer and C N Challies (Forest Service), and personal recollection. In March 1974 and November 1975 approximately the same section was measured (Fig. 14). MBL values indicate that during 1961–75 there was a rise of about 8m in North Branch and 7m in South Branch. Average rates of MBL change are given in Appendix 7.

In accord with upstream recession of the confluence, steepening of channel slopes and channel aggradation, marked increases of ABW have occurred (Table 3). Channel widening has dominated since about 1950 and since about 1966 the average rate of widening has increased. From 1950 to 1975 the increase of ABW was 69%.

From December 1950 to February 1975 a 250-m reach of North Branch immediately up stream of the 1975 confluence, increased from a mean width of 31m to 66m (+113%); a similarly located 300-m reach of South Branch widened from 29m to 50m (+72%).

Consequent upon these channel changes a marked increase in the frequency of occurrence and the magnitude of riparian landslides associated with greywacke rocks has been observed.

PENDLE HILL REACHES

Channel morphology comparisons have been made on four sections about Pendle Hill (Fig. 2, 4). The sections are widely separated on hydraulically different reaches, and for two sections at bridge sites more records are available; therefore these are treated individually.

In the 1944 survey of the then Public Works Department the sections were labelled progressing up stream: W66 (Fletcher's Crossing bridge), W67, W68 (Pendle Hill bridge) and W69.

Fletcher's Crossing Bridge

Between 1916 and 1976 at Fletcher's Crossing bridge, ABW declined from 66.1m to 51.8m due to willow and poplar growth, and MBL rose by 1.0m (Appendices 8, 9).

Pendle Hill Bridge

MBLs and ABWs under Pendle Hill bridge were obtained from the bridge design plan, scaling on oblique photographs and field surveys for a number of dates between 1929 and 1976 (Appendices 10, 11). From 1931 to 1976 MBL rose 2.0m. Reduction of channel

TABLE 3 : Changes of average ABW on a 630-m reach down stream of Waipawa Fork during 1950–75.

Date	No. Years	ABW (m)	ABW Change (m/y)	Remarks
Dec 1950		35.1		Aerial photo 1714/17, SN 541
	16.0		+0.8	
Dec 1966		48.5		Aerial photo 3910/28, SN 1698
	8.2		+1.3	
Feb 1975		59.4		Aerial photo C/20, SN 2800
	24.2	–	+1.0	

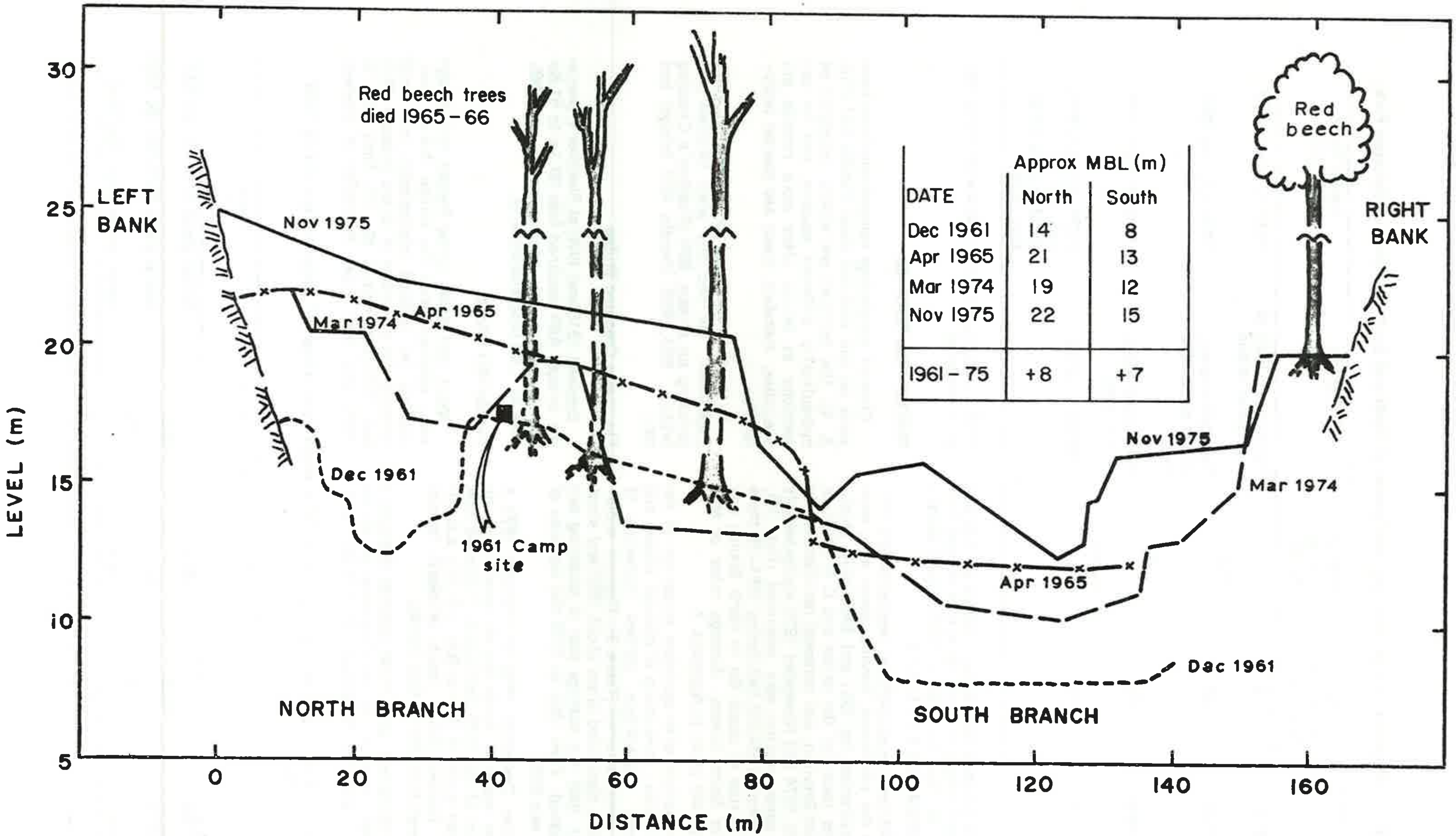


FIG 14 – Channel profiles at the Waipawa Fork section.

width of about 37% took place at bridge construction and subsequent decrease resulted from growth of willows and poplars.

Observations by Mr H Baker, Ongaonga, (pers. comm.) after a flood in the mid 1930s, when the water flowed over the bridge deck, indicated a very high MBL (Appendix 10).

Sections W67 and W69

Section W67 is located 700m up stream of Fletcher's Crossing bridge; W69 is 590m up stream of Pendle Hill bridge. Both were first measured in 1944; the next measurement was in 1976 (Appendix 12). At W69 the MBL has fallen whereas the others show a rise. Longitudinal profile slopes connecting the sections differed considerably at 1944 and 1976. It is considered that the erratic patterns of change are the result, firstly, of the pattern of alluvial deposition during the mid 1930s and secondly of the growth of willows and poplars bordering, and on parts of, the active bed. However the average change from 1944 to 1976 was one of aggradation.

Given also in Appendix 12 are values of ABW for 1943 and 1944 (from aerial photographs) and for 1976. Between April 1943 and May 1944 large increases of ABW occurred. From 1944 to 1976 the overall reduction of ABW has probably been the result of willow and poplar growth.

Summary

The broad patterns of MBL change about Pendle Hill are in agreement; that for Pendle Hill bridge gives more detail. Because of channel constriction both bridge sections must underestimate the magnitude of general channel change. Theoretically, and from measurement, the Fletcher's Crossing section underestimates to a greater degree.

Between August 1960 and October 1976 the average rate of aggradation at the Pendle Hill bridge section was 0.073m/y. Away from channel width constrictions the general rate of MBL rise should exceed 0.073m/y and aggradation is likely to continue on these reaches for some years ahead.

KOWHAI SECTION

Between section W69 near Pendle Hill and McCullough's mill reach no early direct channel measurements are available. However three sets of measurement on the kowhai section (Fig. 2) since March 1975 demonstrate the magnitude of MBL change taking place in middle reaches of the upper Waipawa. Close estimates of ABW have been possible for 1950, 1958 and 1966 by photo scaling. Kowhai section profiles are shown on Fig. 15 and changes of ABW and MBL are given in Appendix 13.

The photos of 1950 and 1958 show that the active channel was at the left bank. The remaining width was a continuous surface covered largely by manuka *(Leptospermum sp.)* numerous kowhai trees *(Sophora sp.)* and scattered totara *(Podocarpus sp.)* poles. Most of the remaining vegetation on the pre-1950 surface now is either dead or not long dead -- much died between March 1975 and June 1976 – which indicates that wide-spread over-deposits of alluvium have drowned the vegetation in very recent years.

Significant aggradation had certainly occurred before cyclone Alison of early March 1975 and since then it has taken place at the extremely rapid rate of 1.35m/y. Observations of similar pre-1950 surfaces along lower reaches confirm that very fast rates of MBL rise are currently occurring widely and resulting in marked increase of ABW.

CHANNEL WIDTH CHANGE OF LOWER REACHES

The length of river concerned is 6.9km. It extends from about section W69 near Pendle Hill to a little up stream of the kowhai section. This length was divided conveniently into three segments. Average ABWs for each channel segment were determined from aerial photographs for 1949, 1950, 1966 and 1972, and from field inspection in 1975 (Appendices 14, 15).

Since 1949 active beds have progressively widened. There occurred short periods when bed widths decreased and one of these is indicated between 1966 and 1972 by the segment C data. From 1950 to 1975 the increase of ABW for segment A was 86%, for B it was 46% and for C it was 24%; the increase for the total length was 63%. Throughout, widening resulted largely from either erosion of, or over-deposition on, earlier alluvial deposits some of which carried well-grown vegetation. It is tempting to interpret the pattern of decreasing percentage change proceeding down stream as being the outcome of time lag of movement of material into and through channel segments. However it is as likely the result of decreasing potential ABWs in the down stream direction because when the 1950 ABW values are expressed as percentages of the 1975 values the respective percentages for segments A, B and C are 54%, 69% and 80%.

Alluvial surfaces carrying manuka of comparable age to that on the kowhai section (established mid 1930s) existed widely down stream to Fletcher's Crossing. In 1976 most of these surfaces either had been covered with deposits of coarse alluvium and the manuka bushes were dead or dying, or they had been washed away. But it was striking that from about 1km up stream of Pendle Hill bridge to Fletcher's Crossing, residual surfaces with manuka of the same age remained intact 0.3 – 0.5m above MBL. They had been periodically overrun by silt-laden flood waters but had not succumbed to the full impact of coarse bed material. Undoubtedly deposition during the 1930s along the lower reaches

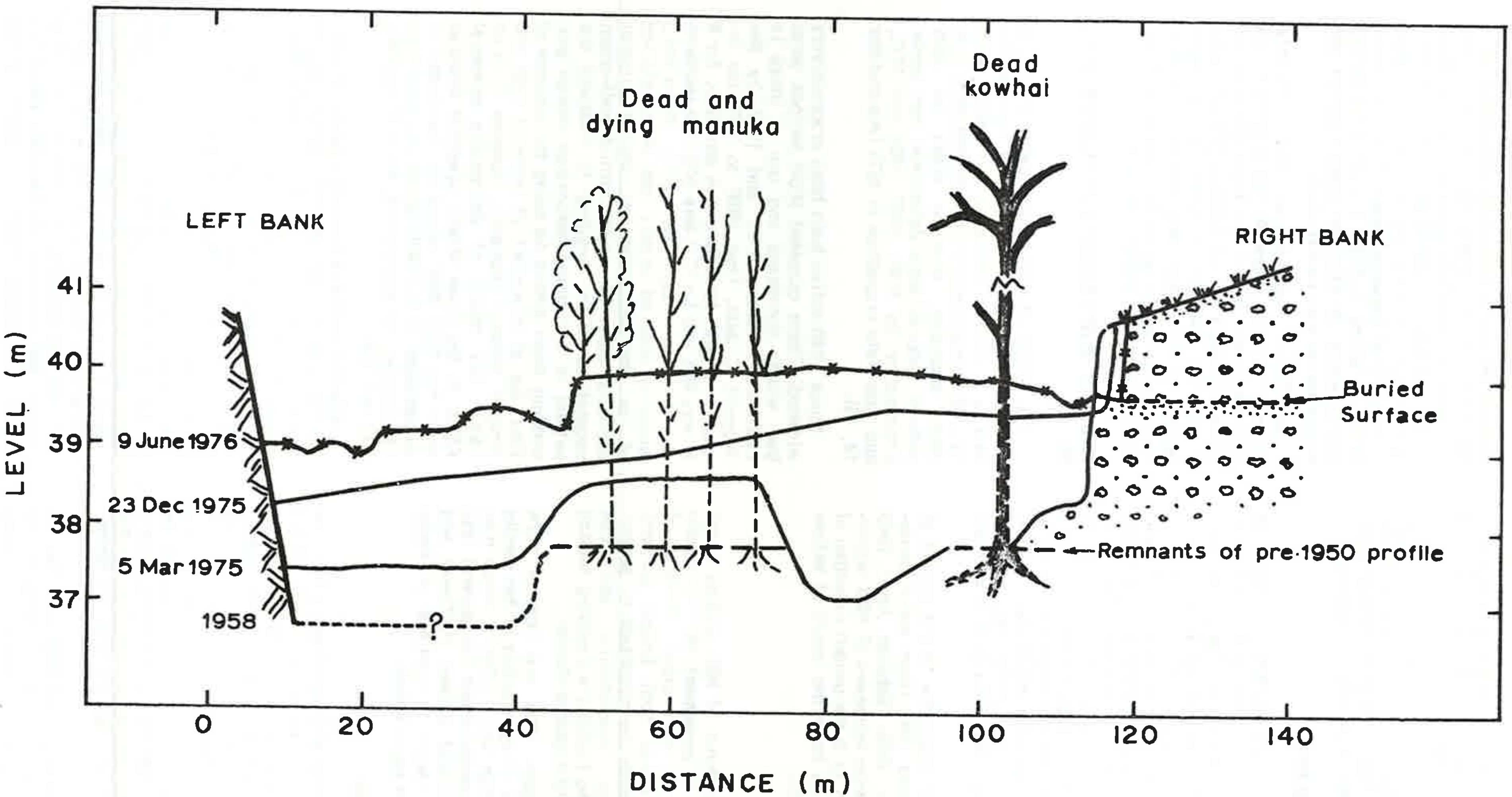


FIG 15 – Channel profiles at the kowhai section.

nearer Pendle Hill reached very high levels as indicated at Pendle Hill bridge.

There is no doubt that the large recorded increases of ABW since 1949 throughout the 6.9-km channel length considered have resulted from increased sediment transport activity and deposition.

MIDDLE AND SMITH STREAMS

Smith Stream basin has an area of 20.6km^2, Middle Stream an area of 14.2km^2 and the upper Waipawa up stream of its confluence has a drainage area of 15.5km^2. Aerial photographs show that since 1950 in the middle reaches of Middle and Smith streams there has been progressive channel widening and an increased incidence of riparian landslides — indications that bed load transport rates have accelerated. In their lower reaches both streams are confined by deep, narrow, boulder-strewn gorges.

Although each stream is transporting coarse bed material, numerous observations after storm rainfall indicate that each is probably supplying only a small proportion of the total downstream coarse sediment load of the Waipawa River. Probably each basin head is supplying smaller rock quantities than the upper Waipawa and of these, large amounts are being stored both up stream of and in the gorges. The upper Waipawa is certainly the source area for the bulk of the bed load which is travelling down stream of Smith Stream.

MANGATAURA STREAM

The Mangataura Stream with a drainage area of 48.3km^2 is not of direct importance to sediment transport and deposition in the upper Waipawa because it enters the Waipawa only 1.1km up stream of the Makaroro River junction; however it displays the same trends of change as the other basins. Aerial photos illustrate that along its upper ESE-trending portion and for some distance down stream of the North Block Rd ford (Fig. 2) progressive channel widening and decreasing sinuosity took place between 1950 and 1975. Adjoining North Block Rd it appears that locally the bed level rose about 2.7m between 1895 and 1955 (late Mr J Carson, pers. comm.) and this trend appears to be continuing.

Further down stream the channel is in a very sinuous gorge through which little fresh load seems to pass; consequently the Mangataura probably contributes very little coarse sediment to the Waipawa River.

CHRONOLOGICAL SUMMARY

For understanding and prediction it is necessary, from the information available, to attempt to discern the major chronological pattern of change throughout the channel of the upper Waipawa River.

Criteria such as MBL and ABW have been used to demonstrate channel change. Rise of MBL or increase of ABW may be adopted to signify channel "deterioration"; reverse changes may be taken to signify "improvement". However a river channel does not function in time as one system but rather as a series of sub-systems. Rising of MBL resulting from increasing rock erosion, sediment transport and deposition may be the dominant longer-term trend, as it has been; but for short periods on some reach sets, or subsystems, the longer-term aggradational trend may be replaced by degradation. For example, from late 1965 to the early 1970s the MBLs at the fork and rimu sections fell (Appendices 6, 7) but on McCullough's mill reach MBLs rose (Appendices 2, 5). Overall for that period the level of activity of sediment transport was high throughout the channel system. Therefore it is not valid to make simple interpretations of overall channel regime from the indications given by one or two channel parameters on one or two reaches. Instead of defining periods of apparent deterioration or improvement of channel form, the aim here is to present a chronological index curve expressing the general periodic rates of channel change which have resulted from, and therefore represent, the periodic levels of activity of sediment transport.

Period definition is approximate because the number of sampling points in time at each site as well as the number of sites is usually inadequate. Consequently actual rate change points do not necessarily coincide in time with those shown (Fig. 16).

Periodic rate of change of channel cross-sectional area (CSA) was the chief criterion used, supplemented by rates of change of MBL and ABW. Where ABW has increased greatly the rate of MBL rise underestimates the rate of real activity in terms of sediment transport and deposition. Furthermore, caution is required in the interpretation of rate of ABW change; greater rates of change can be expected where wide, low alluvial terraces exist compared with where little or none of these remain.

To demonstrate the derivation of periodic rate indices of sediment transport, an example is taken using changes of CSA on section C (Fig. 11) for the four periods since 1960. Periodic rates (m^2/y) of alluvial deposition at the section were: 1960–65, 1·1; 1965–73, 4·6; 1973–May 1975, 7·6 and May–September 1975, 41. Therefore for section C the periodic relative rate indices are 1·1, 4·6, 7·6 and 41 respectively. For graphical presentation these values are expressed as ratios to 10; hence the periodic line slopes are 0·11, 0·46, 0·76 and 4·1.

All site patterns were used to help define rate change points but periodic average rates were determined largely from sites where CSA data could be calculated; and of these McCullough's mill reach became the primary reference site for determining relativity among sites because of its longer and better record.

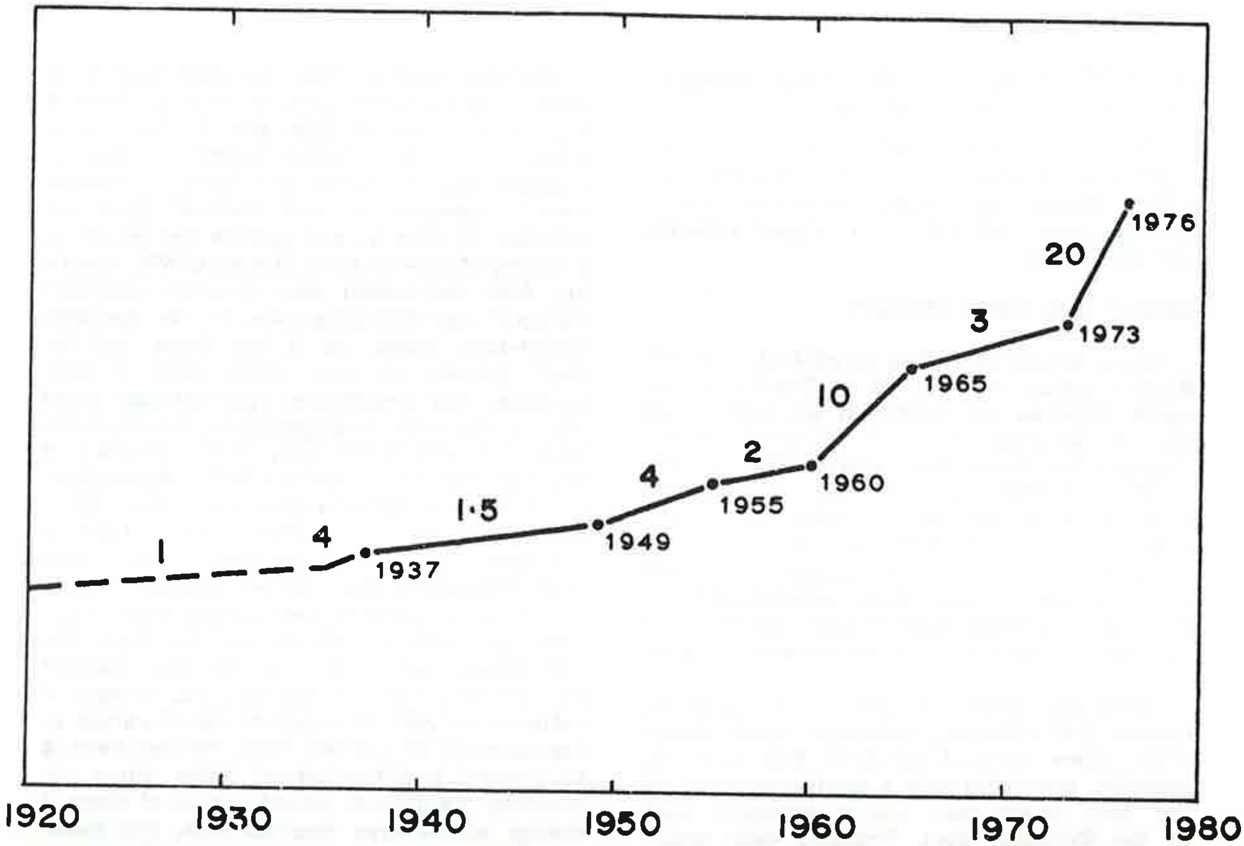


FIG 16 – Broad pattern of relative rates of erosion, sediment transport and deposition in the channel of the upper Waipawa River since 1920. Periodic average relative rate indices are shown.

Throughout the 16-km channel length observed, certain down stream time lags in the aggradation pattern were indicated, but present data are inadequate for clear definition. However there was general chronological agreement for major periods of change and overall trends. Therefore all information was combined to produce one smoothed rate of change pattern for the upper Waipawa River (Fig. 16). Estimated periodic average relative rates of change become rate indices and the trend curve was produced by plotting each periodic gradient using its rate index as a ratio to 10.

The rate indices represent the periodic average relative rates of channel change and hence of coarse sediment transport. For example during 1960–65 the estimated average rate of coarse sediment transport was 5 times that of 1955–60; at McCullough's mill reach from measurements it was about 9 times.

There was a significant burst of channel activity in the mid 1930s, followed by a relatively tranquil period. But perhaps a year or two before 1949 marked the onset of the phase of greatly increased and progressively increasing rates of coarse sediment transport which persisted to 1976 at least. Subsequent rate change points, after which the tempo of change accelerated significantly, occurred about 1960 and 1973.

The chronological pattern since c. 1920 of relative rates of activity of Waipawa River fluvial processes may validly be cautiously applied; but improved understanding and predictive reliability may be expected when this pattern is viewed against the picture of broad change of preceding centuries. Such a picture which was introduced and subsequently referred to by the author (Grant, 1963, 1965, 1975) is to be presented in another paper.

CLOSING COMMENT

Rates of change differ from basin to basin. Rates in the upper Waipawa are probably more rapid than in many basins. If so the upper Waipawa basin is more sensitive to change and therefore should be a good indicator of general change and its trend, particularly on a long-period scale. Perhaps the gross pattern of the upper Waipawa (Fig. 16) qualitatively represents the gross pattern for all basins on the Ruahine Range? Exploration of this possibility is needed. Confirmation of it would demonstrate the value for widespread application of many findings from the upper Waipawa River basin.

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APPENDIX 1: Active bed width (ABW) and mean bed level (MBL) values (in metres) for six channel sections on McCullough's mill reach since 1955.

Date	A		B		C		D		E		F	
	ABW	MBL	ABW	MBL	ABW	MBL	ABW	MBL	ABW	MBL	ABW	MBL
Apr 1955	47.8	18.68	54.6	22.96	72.8	27.38	—	—	—	—	—	—
Dec 1958	48.2	18.62	58.6	22.74	91.4	27.52	—	—	—	—	—	—
Apr 1960	48.8	18.50	58.8	22.70	93.0	27.58	36.0	34.22	35.4	36.70	27.8	39.16
Dec 1964	—	—	—	—	97.8	—	—	—	—	—	—	—
May 1965	51.2	19.12	59.4	23.28	100.6	27.64	—	—	—	—	—	—
Oct 1973	56.4	19.32	66.8	23.32	100.0*	28.02	46.4	34.66	40.2	37.30	30.8	39.78
May 1975	60.0	19.42	77.4	23.20	100.6	28.14	54.2	35.58	39.4*	37.88	29.6*	40.26
Sep 1975	56.0	19.44	78.6	23.80	105.2	28.26	57.0	35.60	39.4	38.06	30.2	40.66
PERIOD CHANGES												
1955–1960	+1.0	−0.18	+4.2	−0.26	+20.2	+0.20	—	—	—	—	—	—
1960–1973	+7.6	+0.82	+8.0	+0.62	+ 7.0	+0.44	+10.4	+0.44	+4.8	+0.60	+3.0	+0.62
1973–Sep 1975	−0.4	+0.12	+11.8	+0.48	+ 5.2	+0.24	+10.6	+0.94	−0.8*	+0.76	−0.6*	+0.88
1960–Sep 1975	+7.2	+0.94	+19.8	+1.10	+12.2	+0.68	+21.0	+1.38	+4.0	+1.36	+2.4	+1.50

* width decrease owing to bank slumping

APPENDIX 2: Reach mean changes of MBL for the 244-m channel reach from section A to C, McCullough's mill reach.

Period	No. of Years	Reach MBL Change (m)	(m/y)	(m/y)
Apr 1955 – Dec 1958	3.7	–0.09	–0.02	–0.03
Dec 1958 – Apr 1960	1.3	–0.04**	–0.03**	
Apr 1960 – May 1965	5.1	+0.46	+0.09	+0.05
May 1965 – Oct 1973	8.4	+0.17	+0.02	
Oct 1973 – May 1975	1.6	–0.01*	–0.006*	+0.17
May 1975 – Sep 1975	0.3	+0.34	+1.13	
1955 – Sep 1975	20 4	+0.83	+0.041	

* Not Significant
** Barely Significant

APPENDIX 3: Reach mean changes of MBL for the 583-m channel reach from section A to F, McCullough's mill reach.

Period	No. of Years	Reach MBL Change (m)	(m/y)	(m/y)
Apr 1960 – Oct 1973	13.5	+0.55	+0.04	
Oct 1973 – May 1975	1.6	+0.33	+0.21	+0.28
May 1975 – Sep 1975	0.3	+0.21	+0.70	
1960 – Sep 1975	15.4	+1.09	+0.071	

APPENDIX 4: Changes of average ABW on the 583-m McCullough's mill reach during 1950–75.

Date	No. Years	ABW (m)	ABW Change (m/y)	Remarks
Dec 1950		29.4		Aerial photo 1715/19, SN 541
	16.0		+1.87	
Dec 1966		59.3		Aerial photo 3910/28, SN 1698
	8.2		+1.60	
Feb 1975		72.4		Aerial photo D/21, SN 2800
	24.2	–	+1.78	

APPENDIX 5: Changes of MBL on section C McCullough's mill reach, since 1937.

Period	No. of Years	MBL Change (m)	(m/y)	(m/y)
mid 1937 – Dec 1950	13.5	0	0	+0.039
Dec 1950 – Apr 1955	4.3	+0.68	+0.16	
Apr 1955 – Apr 1960	5.0	+0.20	+0.04	
Apr 1960 – May 1965	5.1	+0.06	+0.01	+0.044
May 1965 – Oct 1973	8.4	+0.38	+0.05	
Oct 1973 – May 1975	1.6	+0.12	+0.08	
May 1975 – Sep 1975	0.3	+0.12	+0.40	
1937 – Sep 1975	38.2	+1.56	+0.041	

APPENDIX 6: Changes of MBL since 1964 at the rimu section.

Date	No. of Years	MBL (m)	MBL Change (m)	(m/y)
Dec 1964		4.7		
	0.33		+2.2	+6.7
Apr 1965		6.9		
	1.92		–1.1	–0.57
Mar 1967		5.8		
	4.00		–0.2	–0.05
Mar 1971		5.6		
	2.58		–0.3	–0.12
Oct 1973		5.3		
	0.42		+0.5	+1.2
Mar 1974		5.8		
	0.92		–0.4	–0.43
Feb 1975		5.4		
	0.17		+0.7	+4.1
Apr 1975		6.1		
	0.25		+1.3	+5.2
Jul 1975		7.4		
	0.25		+0.5	+2.0
Oct 1975		7.9		
	0.08		–0.3	–3.8
Nov 1975		7.6		
Dec 1964 – Nov 1975	10.9	–	+2.9	+0.27

APPENDIX 7: Average changes of MBL on North and South branches at the Fork section (refer Fig. 14)

Period	No. of Years	MBL Change (m)	(m/y)
Dec 1961 – Apr 1965	3.3	+6.0	+1.8
Apr 1965 – Mar 1974	8.9	–1.5	–0.17
Mar 1974 – Nov 1975	1.7	+3.0	+1.8
Dec 1961 – Nov 1975	13.9	+7.5	+0.54

APPENDIX 8: Changes of ABW and MBL at Fletcher's Crossing bridge since 1916.

Date	ABW(m)	MBL(m)	Remarks
1916	c. 140	–	Before construction
Jan 1917	66.1	9.8	ABW: abutment width x cos 31° (skew) MBL: oblique photo, Waipawa County
May 1944	65.8	10.84	Public Works Department survey
Nov 1973	45.8	10.96	
Feb 1975	45.8	11.00	Bridge section
	51.2	10.96	Section normal to channel immediately down stream of bridge
Apr 1975	51.8	10.70	ditto
Sep 1975	51.8	10.94	ditto
Feb 1976	51.8	10.86	ditto
1917 – Feb 1976	–14.3	+1.0	

APPENDIX 9: Rates of change of MBL at Fletcher's Crossing bridge since 1917

Period	No. of Years	MBL Change (m)	(m/y)
Jan 1917 – May 1944	27.3	+1.0	+0.037
May 1944 – Nov 1973	29.5	+0.12	+0.004
Nov 1973 – Feb 1976	2.3	–0.10	–0.043
Jan 1917 – Feb 1976	59.1	+1.0	+0.017

APPENDIX 10: Changes of ABW and MBL at Pendle Hill bridge since 1929

Date	ABW(m)	MBL(m)	Remarks
May 1929	c. 124	18.9	Before construction
1931	77.7	18.9	Waipawa County records
c. 1936	–	c. 21.5	Per H Baker
May 1944	77.7	20.38	Public Works Department survey
c. 1951	c. 135	20.6	Oblique photo, Miss M Pawson
Aug 1960	77.7	19.7	Oblique photo, Mrs B Wallace
Nov 1973	64.0	20.83	
Feb 1975	64.4	20.68	
Apr 1975	67.0	20.68	
Sep 1975	68.0	20.78	
Feb 1976	66.0	20.90	
Oct 1976	66.9	20.90	
1931 – Oct 1976	–10.8	+2.0	

APPENDIX 11: Rates of change of MBL at Pendle Hill bridge since 1929

Period	No. of Years	MBL Change (m)	MBL Change (m/y)
May 1929 – c. 1936	7	+2.6	+0.371
c. 1936 – May 1944	8	–1.1	–0.138
May 1944 – c. 1951	7	+0.2	+0.029
c. 1951 – Aug 1960	9.3	–0.9	–0.097
Aug 1960 – Nov 1973	13.2	+1.1	+0.083
Nov 1973 – Oct 1976	2.9	+0.07	+0.024
1929 – 1976	47.4	+2.0	+0.042

APPENDIX 12: Gross change of MBL at four sections about Pendle Hill during the 31.8-yr period May 1944 to Feb 1976; and three records of ABW

Section	MBL(m) May 1944	MBL(m) Feb 1976	MBL Change (m)	MBL Change (m/y)	ABW(m) Apr 1943	ABW(m) May 1944	ABW(m) Feb 1976
W66, Fletcher's Crossing	10.84	10.86	+0.02	–	57	66.0	51.8
W67	16.22	17.34	+1.12	+0.035	103	148	94.1
W68, Pendle Hill	20.38	20.90	+0.52	+0.016	46	77.7	66.0
W69	26.86	26.36	–0.50	–0.016	75	193	86.5
Averages :	18.58	18.87	+0.29	+0.009	70	121	75

APPENDIX 13: Changes of ABW and MBL at the kowhai section since 1950

Date	No. Years	ABW (m)	ABW Change (m/y)	MBL (m)	MBL Change (m/y)	Remarks
Nov 1950		23		<37.7		Aerial photo 1716/21
	7.6		+1.45		?	
1958		34		<37.7		Oblique photo, Mrs M J Paterson
	8.4		+0.71			
Dec 1966		40		–	>0.02	Aerial photo 3911/30
	8.3		+7.71			
Mar 1975		104		37.9		Abney level survey
	0.8		+5.00		+1.38	
Dec 1975		108		39.0		Abney level survey
	0.5		+8.00		+1.30	
Jun 1976		112		39.65		
1950 – 1976	25.6	+89	+3.48	+>2.0	–	

APPENDIX 14: Values of average ABW(m) for three channel segments, proceeding down stream (refer Fig. 4) from May 1949 to October 1975

Channel Segment	Length(km)	May 1949	Nov 1950	Dec 1966	Sep 1972	Oct 1975	Channel Sinuosity 1975
A	2.0	–	49	61	–	91	1.13
B	2.3	–	72	78	–	105	1.38
C	2.6	75	86	97	94	107	1.18
	6.9	–	71	80	–	116	1.22

APPENDIX 15: Rates of change of average ABW for three channel segments from May 1949 to Oct 1975.

Period	No. of Years	ABW Change (m/y) A	B	C	
May 1949 – Nov 1950	1.5	–	–	+7.33	
Nov 1950 – Dec 1966	16.1	+0.75	+0.37	+0.68	
Dec 1966 – Sep 1972	5.7	+3.41 (Dec 1966 – Oct 1975)	+3.07 (Dec 1966 – Oct 1975)	–0.53	+1.14 (Dec 1966 – Oct 1975)
Sep 1972 – Oct 1975	3.1			+5.00	
1950 – 1975	24.9	+1.69	+1.33	+0.84	