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WATER & SOIL MISCELLANEOUS PUBLICATION NO. 102

Impact of the Waimakariri River Control Scheme on the River and its Environment

by

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Impact of the Waimakariri River Control Scheme on the River and its Environment

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The evolution of the Waimakariri River since man arrived in New Zealand is described— with particular emphasis on the influence of river control works on the river environment. Vegetative and geologic evidence, old maps, aerial photographs, and topographic and other surveys are used to examine river channel morphology, hydraulic conditions, riparian and floodplain land use and vegetation cover, groundwater recharge, wildlife habitat, recreational use, and landscape value.

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Summary

The Waimakariri River has been selected from several braided rivers in Canterbury, to provide an example of the range of river control problems associated with the protection and development of major river floodplains.

This study should be considered as a pilot study to develop and test methods of surveying and analysing the impact of river control works on the river environment. This is characterised by changes over time in the active river channel morphology, hydraulic behaviour, riparian and floodplain land uses, groundwater recharge, wildlife habitat, recreational use and landscape value.

Each of these components, making up the total river environment, has been surveyed over as long a period as records exist (usually since about 1850). Changes have been quantified, where possible, and reasons for the change have been identified or postulated.

The primary changes that have occurred in the Waimakariri River system dating from about A.D. 1000 are:

(1) A change from a predominantly unconfined alluvial fan, with vegetated islands and riparian lands, having several outlets to the sea via swamps and partly vegetated floodways in the lower reaches to a wide, braided river flowing in a near straight line to a single fixed mouth via an increasingly confined braided channel in its lower reaches.

(2) Accompanying this change has been an approximate doubling of the available stream power at the 100 year design flood in the middle and lower reaches.

(3) A very large increase in the value of the resources protected by the river control scheme. This increase is now occurring at a much faster rate than the value of the river control works themselves, because the major control works are nearing completion.

(4) A probable major decrease in the rate of recharge from the river to some groundwater aquifers downstream from Halkett, and extending towards Christchurch.

(5) A change in the character of wildlife habitat from an environment well suited to the needs of the existing native bird and fish species at the time of Polynesian settlement, through an open, almost treeless environment in the middle reaches at the time of European settlement, to the present semi-wilderness environment, more suited to the requirements of the introduced species now populating the river and riparian lands.

(6) A major increase in all types of recreational use of the river and riparian lands, particularly in the last fifteen years. This is associated with increased conflict between recreational users, such as jet boat enthusiasts and rafters; picnickers and trailbike riders.

(7) A slow, but increasing improvement in the landscape values of the riverscape since the relatively bare 'desert like' landscapes of the middle reaches at the time of European settlement. This is mainly associated with the provision of shelter and visual variety provided by the willows, poplars and conifers planted primarily for river control purposes. These are now the key elements in the use of the riparian lands for recreation.

This study found reasons to endorse existing river management policy which aims at encouraging the use of the middle and upper reaches of the river (mainly upstream of Halkett Groyne) as a sediment storage area, where finer sized sediments are deposited in planted bermlands, while still allowing the bulk of the gravels to move downstream for use as a commercial gravel resource and to maintain stable bed levels. In this way, the potential productivity of bermlands will increase through fine sediment deposition, and part of the value of potentially fertile sediments eroded from the riverbed upstream in the upper catchment will not be lost to the sea.

1 Introduction

There is growing pressure from the forestry and agricultural sectors to utilise for productive purposes the large areas of undeveloped land—frequently covered by gorse, broom, rough pasture and bare gravel—along river banks. At the same time, public awareness is growing of the value of the river environment for other purposes, particularly recreation, provision of habitat for wildlife and fish, and as a scenic resource. In the past, the primary function of river control schemes has been to protect floodplain developments from flooding and to allow their maximum use for primary production. However, as the demand for protection or enhancement of the river environment for other purposes grows, it is increasingly desirable that river control schemes be designed with reference not only to the benefits of flood protection and increased agricultural production, but also in the context of multiple use management of the river environment.

A basic need, therefore, is to establish and compare the impact of past river control projects on the river environment, and on its value for recreation, as wildlife or fish habitat, and as a scenic resource. This in turn requires a methodology for data collection and a unifying principle which would enable comparison of the response of different rivers to different types of river control works. Channel morphology and energy expenditure provide a context within which different rivers may be compared and the effects of different management strategies evaluated. Stream power per unit width is a measure of the rate at which energy is expended in a river per unit area of riverbed, and varies directly with discharge and slope, and inversely with channel width (Leopold *et al.,* 1964, p. 178). Stream power thus provides a simple index for comparing different rivers (Hey *et al.,* 1982, p. 434), but it is believed that it may also provide a yardstick against which the effects of river control work can be compared. River control works may themselves be regarded as a form of energy expenditure; human labour and the use of fossil energy are required to control the energy expended by a river as it transports sediment, erodes its banks, and shapes its channel.

In 1981 the Hydrology Centre commenced work on a study of the effectiveness and effects of river control works. An initial requirement was seen to be the development of a standard method for collecting data which would document, both quantitatively and qualitatively, the response to control works of the hydraulic and other characteristics of a river and its environment. This would permit comparison, between rivers having different characteristics and/or subject to various types of control work, of the effects of river control, and development of a general understanding of these effects. Visits to ten catchment authorities, indicated that data are available for 15–20 rivers, which are sufficiently comprehensive to allow such a comparison to be carried out.

To develop a standard data collection method, it was decided to work initially with a single river. The Waimakariri River, downstream of its Lower Gorge, was selected for detailed study because there is an excellent 120 year record of its behaviour. The river typifies many of the problems with management of gravel bed rivers, and it is set in a productive and well-populated floodplain.

Unfortunately, because of staff movements and changing research priorities, no additional rivers have been studied, and the comparison that was originally envisaged is not yet possible. Nevertheless, it is considered that the comparative approach has great potential for providing understanding and a capability for prediction of river response to control works, and it is hoped that the necessary data for a number of rivers will ultimately be assembled. The purpose of the present report is therefore:

(1) to place on record the material assembled for the Waimakariri and
(2) to provide a model for future exercises which will assemble comparable data for other rivers.

Because only one river has been studied, no formal comparison of different data collection procedures has been presented. However, during data collection, analysis, and preparation of the report, many options were considered, and we believe that the types of information presented herein clearly convey the changes in river characteristics which have been associated with control of the Waimakariri River.

2 The River and its Environment

2.1 Geomorphology

The Waimakariri River, which flows eastward from the Southern Alps of the South Island, has a maximum catchment elevation of 2402 m (Figure 1). It emerges on to the upper Canterbury Plains from the Lower Gorge, at an elevation of about 250 m, 57 km from the sea. From the Lower Gorge it flows in a gradually shallowing trench, cut through extensive Pleistocene outwash gravel deposits, for 25 km to Halkett Groyne. Here, the longitudinal profile of the river, which has a slope of about 0.005—m/m, intersects that of the highest surface of the Plains. Downstream from Halkett Groyne, the river is constructing a new alluvial fan. Before 1857, channels diverged from the Halkett reach across the fan surface; there was no single river mouth, the water reaching the sea at the present Brooklands Lagoon, Avon-Heathcote estuary, and via the Halswell River and Lake Ellesmere (Figure 2). Indeed, the line of steepest slope would tend to lead the river directly to Lake Ellesmere, rather than via the northern course it happened to occupy at the time European settlers began to fix its course. Jobberns (in Speight *et al.*, 1927) wrote:

> "... old river banks and bare stony lands of characteristically recent river bed indicate that, at no very distant date, the Waimakariri flowed to Lake Ellesmere ... at a time when the lake itself extended somewhat further inland."

Cox and Mead (1963) stated that:

> "It is now clear that the Waimakariri has reoccupied and carried gravels in old courses linking with Heathcote, Avon and Halswell Rivers as recently as 900 years ago and with the Avon and Halswell in the past 100 to 300 years."

Radiocarbon dating of buried wood and peat (under the present floodplain in the Templeton/Yaldhurst area) indicates two recent periods of sedimentation: the first beginning about 900 years B.P. and lasting about 200 years, the second beginning about 300 years B.P. Sedimentation is now confined by stopbanks to the lower reaches of the river.

The Waimakariri floodplain is essentially a large alluvial fan, which has recently been confined by river control works. To facilitate analysis, the floodplain below the Lower Gorge was divided into 7 reaches (Figure 1), each having a characteristic combination of channel form, floodplain width and slope:

Location	Reach No.	Length	Classification
Sea to Crossbank	1, 2, 3	17.5 km	Lower fan and floodplain zone
Crossbank to Halkett Groyne	4, 5	14.7 km	Middle fan zone
Halkett Groyne to Lower Gorge	6, 7	24.8 km	Upper entrenched fan zone (or upper reach)

2.2 Soils and Vegetation

For the purposes of this study, only the area potentially affected by sedimentation and flooding is considered, that is, the area bounded by high terraces in reaches 6 and 7, by low river banks and terraces in reach 5, and defined by recent soils in reaches 1–4. The total area of floodplain, so defined, is 560 km^2 (including the riverbed, lagoons, estuaries and urban/industrial land).

Floodplain soils were grouped (Figure 3a) using data supplied from three soil maps and discussion with Ministry of Works and Development (MWD) land resource survey staff.

Data sources used were:

(1) Soils of the Downs and Plains of Canterbury and North Otago. *Soil Bureau Bulletin 14,* DSIR, 1967.

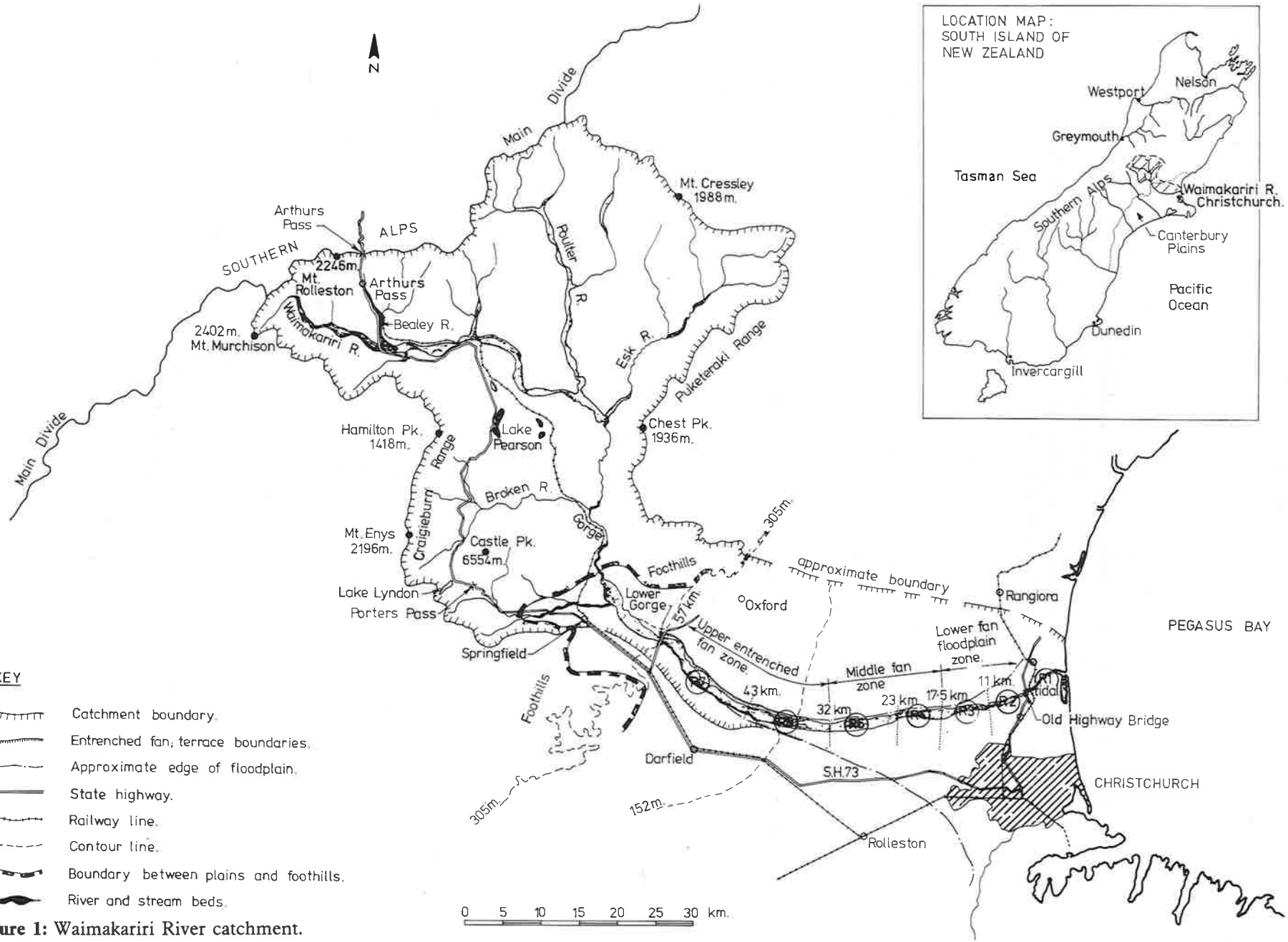


Figure 1: Waimakariri River catchment.

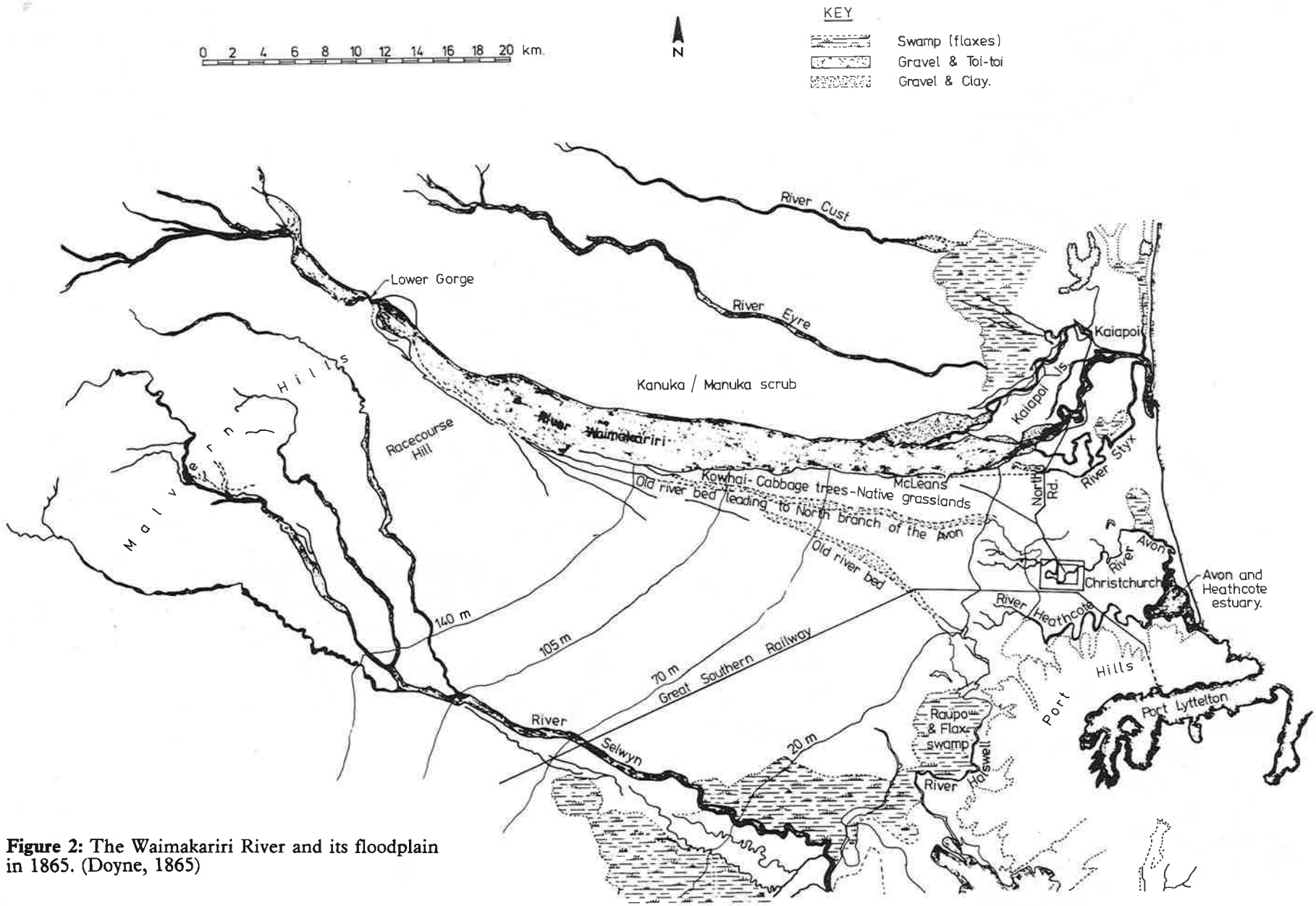


Figure 2: The Waimakariri River and its floodplain in 1865. (Doyne, 1865)

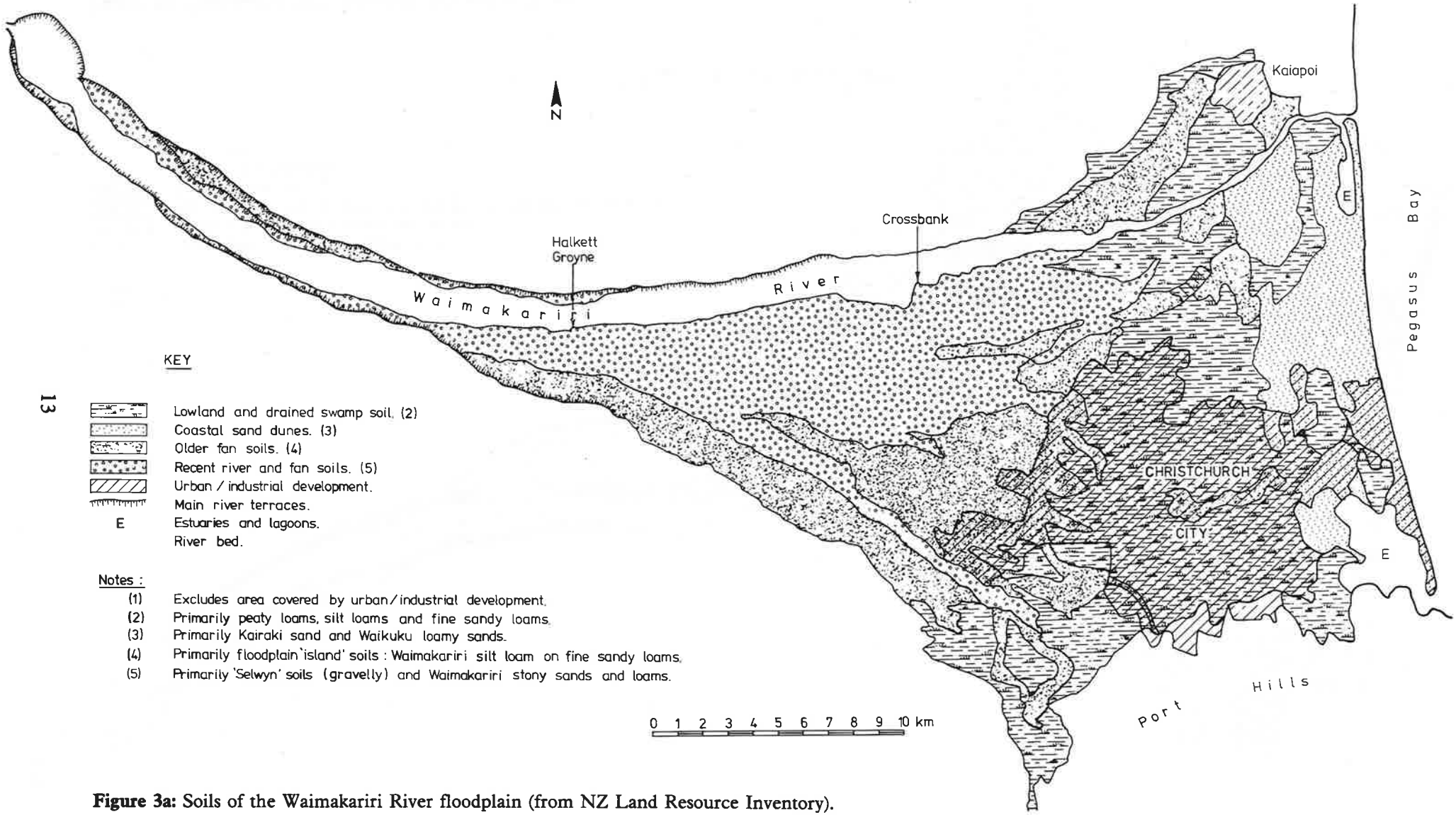


Figure 3a: Soils of the Waimakariri River floodplain (from NZ Land Resource Inventory).

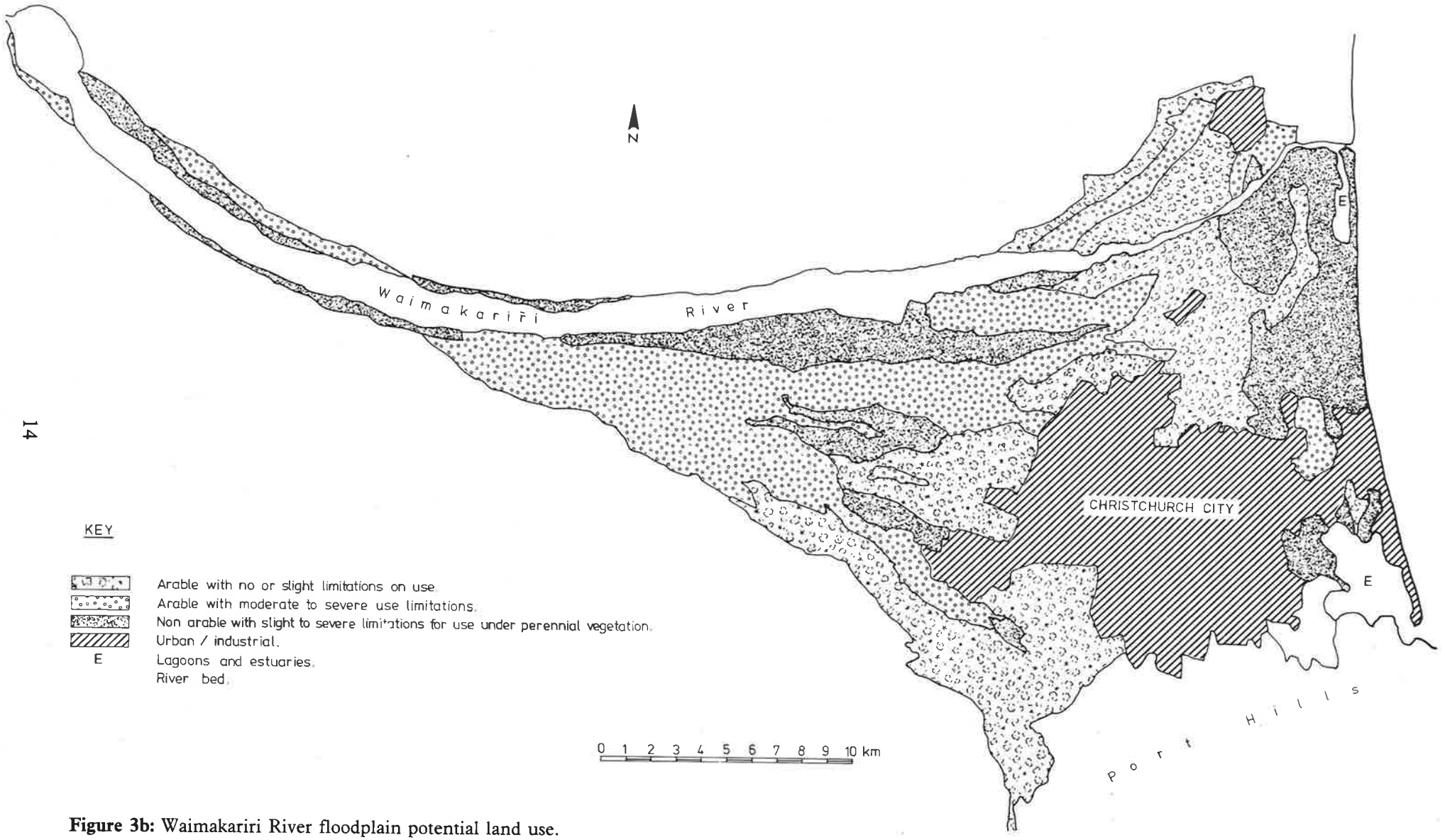


Figure 3b: Waimakariri River floodplain potential land use.

(2) Soils of the Christchurch Region; Raeside and Rennie: *Soil Survey Report No. 16,* DSIR, 1974.

(3) Soil Map of Paparua County; *NZ Soil Bureau Publ. 485,* DSIR, 1971.

To obtain a uniform, consistent map from a synthesis of these data sources, selected soil units were combined into 4 groups, using data from the New Zealand Land Resource Inventory (NZLRI), and the MWD LADEDA system.

The upper and middle fan zone is composed primarily of Selwyn and Waimakariri soils, which range from silt loam and fine sandy loams formed on islands and by overbank flow to gravelly and stony sands and loams marking the course of old riverbeds (Figure 3a). Around the margin of the fan are found Waimairi and Taitapu soils—peaty loams and loam peats, and sandy loams to clay loams, respectively. These were formed in lowland and swampy areas where fine sediments and organic matter were being deposited, and now form the base of the roughly triangular shaped floodplain. Along the coast is an area of Kairaki soils forming coastal sand dunes.

Apart from the coastal sand dunes, the soils comprising the floodplain and fan were laid down by the river or by associated depositional processes at the margin of the fan, yet their fertility, susceptibility to flooding, drainage and other characteristics, vary markedly. Approximately 25% (134 km^2) of the floodplain area is composed of Class I or II land, with no or slight limitations to arable use; another 25% (130 km^2) is Class III or IV, with moderate to severe limitations to arable use; and the remainder is Class V–VIII, non-arable with slight to severe use limitations (97 km^2), riverbed (71 km^2), or has been developed for industrial or urban uses (116 km^2). The land use capability (LUC) classes of the NZLRI correspond closely to the broad soil groups (Figures 3b and 3a, respectively). Of the total area, the group 2 and 3 soils—the coastal sands and the older fan soils—are relatively flood-free.

The vegetation existing before Polynesian settlement (Figure 4) has been reconstructed from evidence of relict native vegetation on stable sites on the fan and floodplain (Cockayne, 1927; Cox and Mead, 1963; Johnson, 1961; and Molloy, 1971 and pers. comm.). Until about 1000 B.P. the Waimakariri floodplain was at least partially covered in a scrub/forest community, through which passed an anastamosing system of channels flowing between stable vegetated banks. Under these semi-forested or swampy conditions, deposition of fine and coarse sediments would have been both widespread and rapid.

The dominant vegetation communities under natural conditions were (Figure 4):

(1) Podocarp dominant forest: Kahikatea (*P. dacrycarpus dacrydioides*) on swampy sites, with rimu (*Dacrydium cupressinum*), matai (*P. spicatus*), totara (*P. totara*), and other native understorey shrubs (eg, coprosmas, broadleafs) on the fertile, well-drained soils.

(2) Mixed forest: Podocarps (mainly kahikatea and matai), kanuka (*Leptospermum ericoides*), kowhai (*Sophora microphylla*) on well-drained soils, predominantly sandy/silt overlying gravels. Flaxes, cabbage trees and coprosmas also occurred.

(3) Kowhai/Kanuka shrublands: Generally on shallow sandy/gravelly areas with little or no soil development—usually in the middle and upper riparian zones, subject to occasional destruction by erosion and sedimentation. Areas of tussock grasslands also occurred within these areas as did pockets of cabbage trees, flaxes, toetoe and hardy coprosmas.

(4) Kanuka dominant with areas of kowhai, flax *(Phormium tenax),* toe toe *(Cortaderia* spp.), cabbage trees *(Cordyline australis),* and open, native grasslands. These were mainly on drier sites of old river gravel deposits.

Remnants of these communities are preserved at several sites along the north and south banks of the river, Dean's Bush and other locations in Canterbury, and wood remnants are regularly excavated from the fan area. It has been postulated that they developed several thousand years ago under a more favourable climate, but with subsequent cooling their vigour has declined (Cox and Mead, 1963; Molloy, 1971). Because of the low rainfall and open drainage of much of the Waimakariri fan, these communities were probably very sensitive to climatic change, and also to the activities of Polynesian settlers; fires set for the

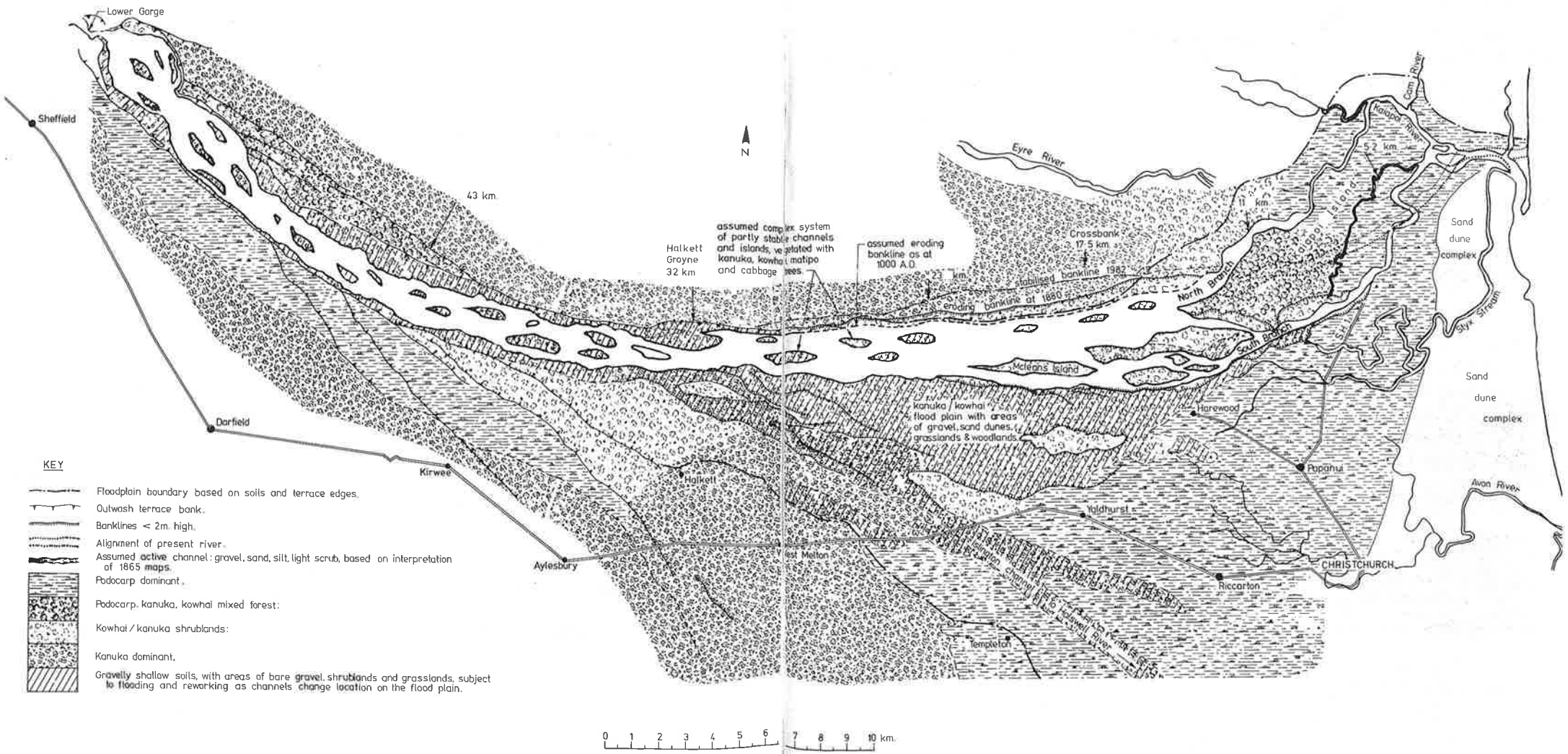


Figure 4: Waimakariri River floodplain vegetation: 1000 B.P.

purposes of hunting would have been very destructive. Consequently, the first European settlers were confronted with a landscape which was bare and open, except for areas of native shrubs along the upper floodplain and swamps and forest remnants on the fan and around its margin (Molloy, 1971). Dobson (1881) regarded the Waimakariri as a "vast area of profitless shingle" and "barren shingle beds".

2.3 Hydrology

Of the total catchment area of 3365 km², 2460 km² lies upstream of the Lower Gorge, with a mean elevation of 1065 m. Of this area, 6.27 km² is covered in permanent snow, and snow contributes about 25% of the annual precipitation in the headwaters above 1500 m (T. J. Chinn, MWD, pers. comm.); below this level, the proportion of snowfall to rain diminishes rapidly. Mean annual precipitation ranges from more than 5000 mm in the northwestern headwaters to 900 mm in the Castle Hill Basin, immediately above the Waimakariri Gorge, and is about 500 mm in the central Canterbury Plains.

The mean annual discharge at the Old Highway Bridge during the period 1967–81 was 116 m³/s (Table 1). Mean monthly discharges range on average from 71 m³/s in February to 173 m³/s in October. The minimum recorded mean monthly discharge was 26 m³/s in March and in April 1971. The minimum recorded daily flow was 21 m³/s, and the maximum estimated flow was 3990 m³/s, in December 1957. Because of irrigation abstractions and losses to groundwater, there is a mean annual flow loss of 9 m³/s from the Gorge to the sea, the effects of which are most apparent during periods of prolonged low flow. The flow duration curve (Figure 5) indicates that discharge exceeds 390 m³/s for 5% of the time.

Table 1: Mean monthly discharge for the Waimakariri River at Old Highway Bridge[1]

Year	Mean Monthly Discharge (m³/s)												Mean Annual Discharge
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	
1967	93	65	131	181	100	50	78	164	106	119	344	209	137
1968	93	112	110	128	141	76	98	111	107	277	228	137	138
1969	59	43	61	73	59	50	56	59	227	75	61	124	79
1970	100	48	63	67	46	61	70	157	427	134	116	81	114
1971	54	31	26	26	37	105	48	49	115	263	129	88	81
1972	67	36	79	101	137	64	95	64	157	307	172	104	116
1973	59	36	31	80	115	90	41	119	108	105	159	60	84
1974	61	74	69	224	88	108	150	89	140	186	181	86	121
1975	84	82	111	216	198	147	133	177	166	163	152	97	144
1976	93	85	59	45	93	145	91	85	103	130	111	167	101
1977	188	109	70	60	101	94	96	58	83	118	120	91	99
1978	80	40	66	134	141	86	118	190	227	118	143	107	127
1979	79	97	92	117	227	89	89	136	154	192	148	263	141
1980	225	134	141	121	99	136	83	158	231	158	175	127	149
1981	69	75	123	93	82	113	89	70	110	254	112	157	113
MEAN	94	71	82	111	111	94	89	112	164	173	157	127	116
MIN	54	31	26	26	37	50	41	49	83	75	61	60	79
MAX	225	134	141	224	227	147	150	190	427	307	344	263	149

Note: To convert these flows to equivalent flow at the Lower Gorge, increase values by 5 m³/sec for data recorded since 1972 and by 13 m³/sec for data prior to 1972. This allows for abstractions plus groundwater losses (the latter have decreased since 1972). A mean of 9 m³/sec could be added to the overall mean monthly flow to give the equivalent flow at the Lower Gorge.

Annual maximum floods for the period 1930–81 (Table 2, from Reid and Poynter, 1982) were used to estimate flood frequencies (Figure 6). The Gringorton formula was used to plot these data. The mean annual flood is 1709 m³/s, and the flood with a recurrence interval (RI) of 100 years is estimated to be 4300 m³/s. As additional data have become available, flood statistics have changed, primarily because there have been no large floods since 1957. Thus,

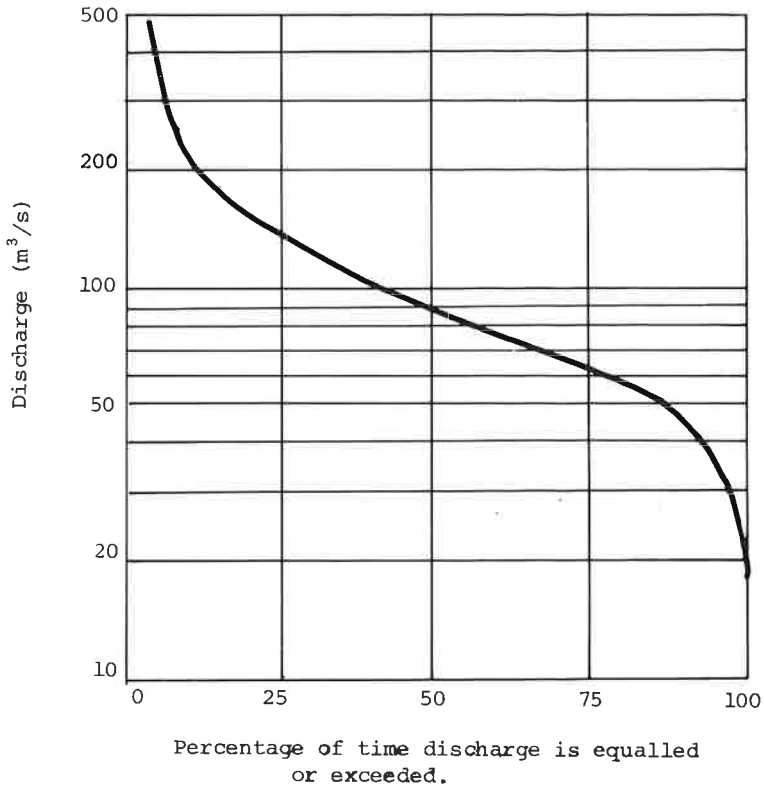


Figure 5: Flow duration curve for Waimakariri River at Old Highway Bridge 1967–81. (Data: NCCB)

Table 2: Maximum annual floods for the Waimakariri River at Old Highway Bridge (from Reid and Poynter, 1982)

Year	Maximum Discharge (m^3/s)	Year	Maximum Discharge (m^3/s)
1930	1330	1956	2210
1931	2040	**1957**	**3990**
1932	1300	1958	1440
1933	2210	1959	1050
1934	1500	1960	1390
1935	1300	1961	960
1936	**3170**	1962	1100
1937	2210	1963	1280
1938	2010	1964	1420
1939	1020	1965	1230
1940	**3740**	1966	850
1941	1640	1967	2054
1942	1700	1968	1038
1943	1080	1969	1108
1944	1300	1970	2503
1945	1440	1971	1190
1946	1610	1972	1676
1947	2100	1973	1000
1948	1810	1974	1130
1949	1360	1975	1772
1950	**3090**	1976	1317
1951	2100	1977	1120
1952	1220	1978	1253
1953	1300	1979	2888
1954	1610	1980	1384
1955	2320	1981	1292

Note: Major flood events in bold type.

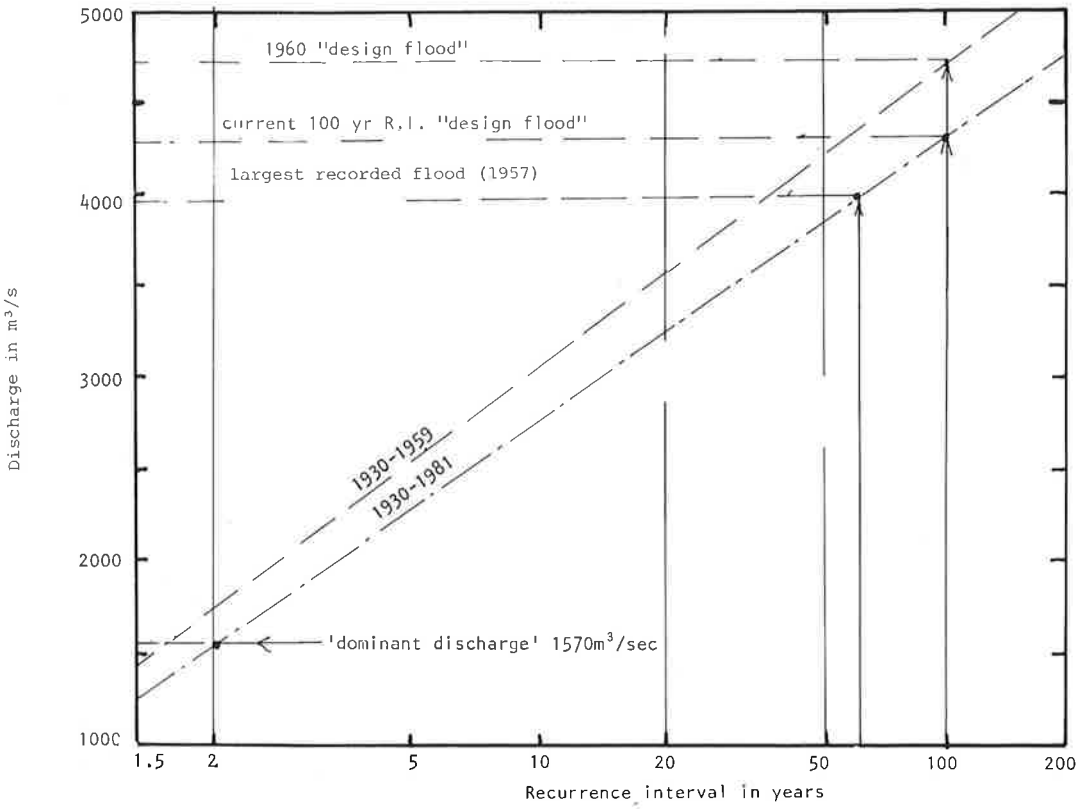


Figure 6: Flood frequency curve for Waimakariri River at Old Highway Bridge. (Data: NCCB)

for example, the 100 year flood was estimated to be 4730 m³/s on the basis of 1930–59 data (Henderson, 1960), which is 10% greater than the present estimate.

Floods result from heavy rain, sometimes combined with snowmelt, associated with moist nor'westerly winds. The largest flood on record was caused by a storm in December 1957, during which 328 mm of rain fell at Arthur's Pass in 24 hours, resulting in an estimated flood peak of 3990 m³/s at the Old Highway Bridge. About 60% of the precipitation fell on 30% of the catchment, mainly in the western headwaters (Hayward, 1967).

Major floods reach the Lower Gorge about 24 hours after rain commences at Arthur's Pass. Before construction of flood control works, flood flows diverged below Halkett Groyne through a network of flood channels, reaching an area of swamps along the margin of the fan (Figure 2). Flood waters were then gathered by lowland rivers — the Styx, Avon, Heathcote, Halswell, and North and South Branches — and conveyed to the sea. Because of storage in the swamps, losses to groundwater and evaporation, a significant portion of the runoff would not have reached the sea as stormflow. In the early years of settlement, the uncontrolled lower reaches of the river created severe problems for the settlers, when large areas of what is now the city of Christchurch were covered with water up to 1.2 m deep (Figure 7).

The vegetation cover of the upper catchment has been severely modified (Molloy, 1967), with a decline in forest cover from at least 60% to less than 30%. However, lack of long-term hydrologic records makes it difficult to demonstrate an impact of the resulting change in water storage upon flood flows. Summer low flows could now be higher than prior to the loss of vegetative cover because of a reduction in transpiration from the forest cover.

2.4 Erosion and Sedimentation

There are two main schools of thought regarding the source of sediment carried by the Lower Waimakariri River. The first, more traditional view, is that the bulk of sediment comes from the upper catchment; the second is that most is supplied by local bed scour and

bank erosion downstream from the Lower Gorge, in reaches 4–7 (Figure 1). Griffiths (1979) estimated an average annual rate of sediment supply from reaches 4–7 of at least 237,000 m^3/yr. This does not include deposition or erosion of the bermlands as surveyed at cross-sections by North Canterbury Catchment Board (NCCB) staff over the 50 years of survey records.

Data supplied by the NCCB (Reid and Poynter, 1982, Table II) from cross-section comparisons show that sediment movement in reaches 4–6 (including berms and islands as surveyed over the full cross-section width), has increased from 6500 m^3/yr deposited between 1930 and 1955 to 129,000 m^3/yr eroded between 1973 and 1981. In the absence of reliable measurements of sediment transport through the Gorge, it is difficult to draw a firm conclusion, although it is clear from the above data that a combination of channel, bank and bermland erosion is supplying a large volume of sediment to the lower reaches.

The widely held view that vegetation destruction and accelerated erosion have increased sediment loads in such rivers as the Waimakariri has been questioned by recent studies. For example, Mosley (1979) indicated that most sediment reaching the headwater channels of the Harper-Avoca River (in the Rakaia Catchment) comes from "geologic" erosion features which are controlled more by lithology, geomorphology and climate than by vegetation cover. Analysis of data from the NZLRI for the Upper Waimakariri also suggests that any change in degree of erosion has not contributed directly to any apparent increase in sediment transport rates in the river. The area of gullies, the major sediment contributors, on present forested areas is only 1.72 km^2 (2.6% of the forest area), and the area on tussock grassland which was formerly forested is only 0.22—km^2 (0.3% of the area). Present forests lie mainly in the steep, western part of the catchment, with an annual precipitation greater than 1750 mm, and it is considered that the area of gullying is again related primarily to climate, geomorphology and lithology. However, this does not imply that a vigorous vegetation cover is not important to the hydrologic and sediment balance on the remaining land at present free from gullying.

Figure 7: The Avon River at the Gloucester Street Bridge during the 1868 flood. (Christchurch Press)

Three sedimentation environments may be identified on the active floodplain downstream from the Lower Gorge. The upper zone (reaches 6 and 7) is essentially a zone of transfer and erosion, which conveys sediment leaving the Lower Gorge and is a source of additional sediment from bed scour and erosion of the river banks and terraces. Temporary sediment storage is provided by the floodplain, and by construction of bars and islands in the active channel.

The second environment, the middle fan zone (reaches 4 and 5), is roughly triangular in shape, diverging from its apex near Courtenay, and includes fingers of gravel which extend down into the swamp areas at the toe of the fan. Deposition and reworking of sediment during floods, both within the active channel network and on the fan surface, were responsible for construction of the fan as banks eroded and channels shifted. The roots of the natural shrub-forest vegetation community would probably have reduced the intensity of these processes below that following vegetation removal after the arrival of the Polynesians.

The third sedimentation environment, the lower fan and floodplain zone, below the present Crossbank (reaches 1 to 3), had a branching, anastamosing channel network. Coarser sediments were deposited on the fan, along old flood channels and at the margin of the fan, which is approximated by the 20 m contour (Figure 2). Fine sediments settled out on banks and islands on the fan and in swampy areas around the margin of the fan. Soil surveys (Figure 3a) indicate that no coarse sediment reached the sea.

Sediment size decreases in the downstream direction (Figure 8). There is at present a change from gravel to silt on the riverbed approximately 2.5 km from the sea; before Polynesian settlement, this transition probably was 8–12 km from the sea, at the toe of the fan (based on soil maps). Speight *et al.* (1927) record a gravel tongue moving downstream to about the 5 km mark by 1927. From 1927 to 1960 this tongue of gravel, marking the transition from a gravel bed to a silt bed river, moved to its present location (Reid and Dick, 1960).

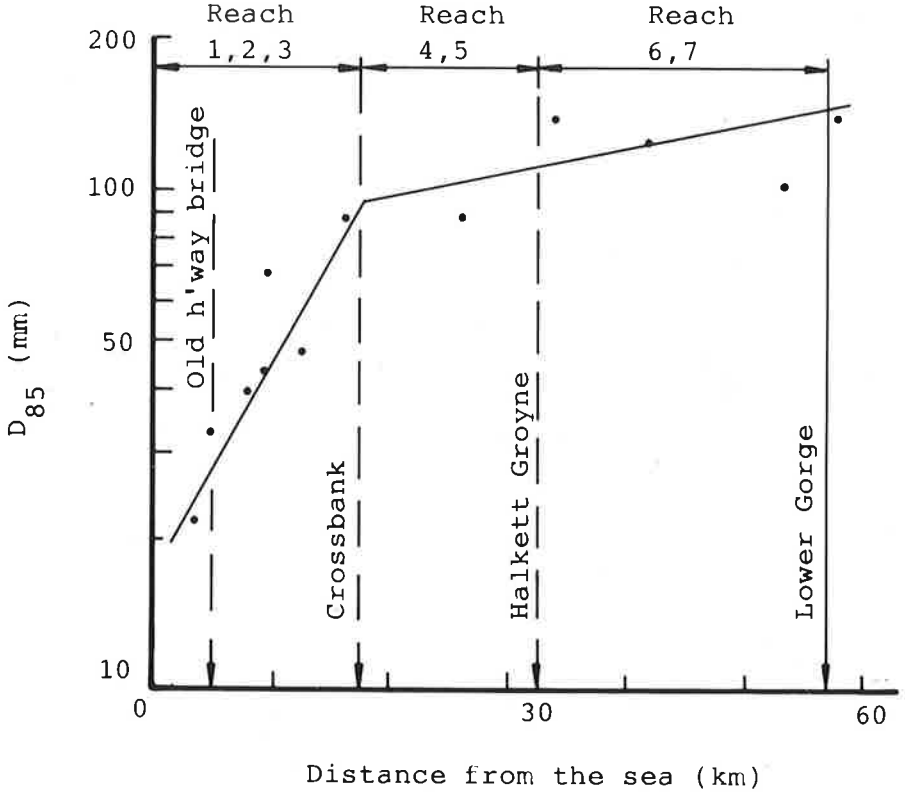


Figure 8: Variation of sediment size D85 (grain size at which 85% is coarser) along the Lower Waimakariri River.

3 History of River Control Works

3.1 Provincial Government (1840–1880)

The *Lyttelton Times* of 12 February 1859 stated that:

"It would appear from unmistakable indications that the Waimakariri River, for about the first twenty miles of its course upstream, has not been in the habit of long sticking to one bed; in colonising the country we must civilise the river".

During the period 1840 to 1880, the main works carried out were the construction of embankments on the south bank to block flood overflow channels leading to the site of the developing town of Christchurch (Figure 9). These works, administered initially by the Provincial Government and from 1869 by an appointed Board of Conservators, reduced the frequency of floods reaching Christchurch, but increased problems in the lower reaches by passing greater volumes of water to the Kaiapoi Island area. Five floods appear to have reached the Avon River between 1848 and 1868 but there is no record of flooding in the Avon River from Waimakariri overflows since 1868.

The physical changes to the river during this period were:

(1) Continued erosion of sections of the north and south banks, mainly in reaches 3 and 4.

(2) The development, partly by natural erosion processes and partly by the activity of settlers on Kaiapoi Island, of the "new channel" and the appearance of Coutts Island. A water supply ditch constructed to supplement the flow to a flour mill captured part of the 1868 flood, and dissected Kaiapoi Island. This has now been developed into the present main channel.

(3) The development of a new channel through Stewarts Gully. This was also initiated during the 1868 flood, which caused major property losses, several drownings and resulted in the need to build a new railway bridge.

3.2 South Waimakariri River Board (1880–1923)

In 1880, the South Waimakariri River Board was formed to administer the district south of the centre line of the South Branch of the river. It was granted title to 5542 ha of Endowment Lands by the Crown (Figure 19) which were leased out, primarily for grazing. This area consisted mainly of riverbed, old flood channels, gravelly grasslands and scrub.

Two major floods occurred in 1887 and 1905, but no flood waters reached Christchurch.

Significant occurrences between 1880 and 1923 were (Figure 10):

(1) Major bank erosion on the north bank, primarily in reaches 3 and 4. Limited protection works were constructed to combat this erosion.

(2) Flooding on Coutts and Kaiapoi Islands.

3.3 Waimakariri River Trust (1923–1946)

The Waimakariri River Improvement Act 1923 established the Waimakariri River Trust, whose district included land on the north and south banks of the river, from the sea to the Gorge.

The major problem during this period was continued aggradation upstream of Coutts Island (reach 3). After much controversy, F. C. Hay's No. 2 River Control Scheme was approved by the Trust. The scheme recommended the straightening of the lower reaches via Wrights Cut and a system of stopbanks, groynes and extensive tree planting in wide belts along the river banks. The Nelson Report (1928) agreed in principle with this approach, and a loan poll was carried in October 1928. The direction of all subsequent control works was set by the plans devised in Hay's scheme.

In February 1940, a flood of 3740 m^3/s (RI = 40 years) broke the stopbanks at the Crossbank and near Whites Bridge, but damage was generally less than for earlier floods of similar size.

The main events during this period were (Figures 10, 11)

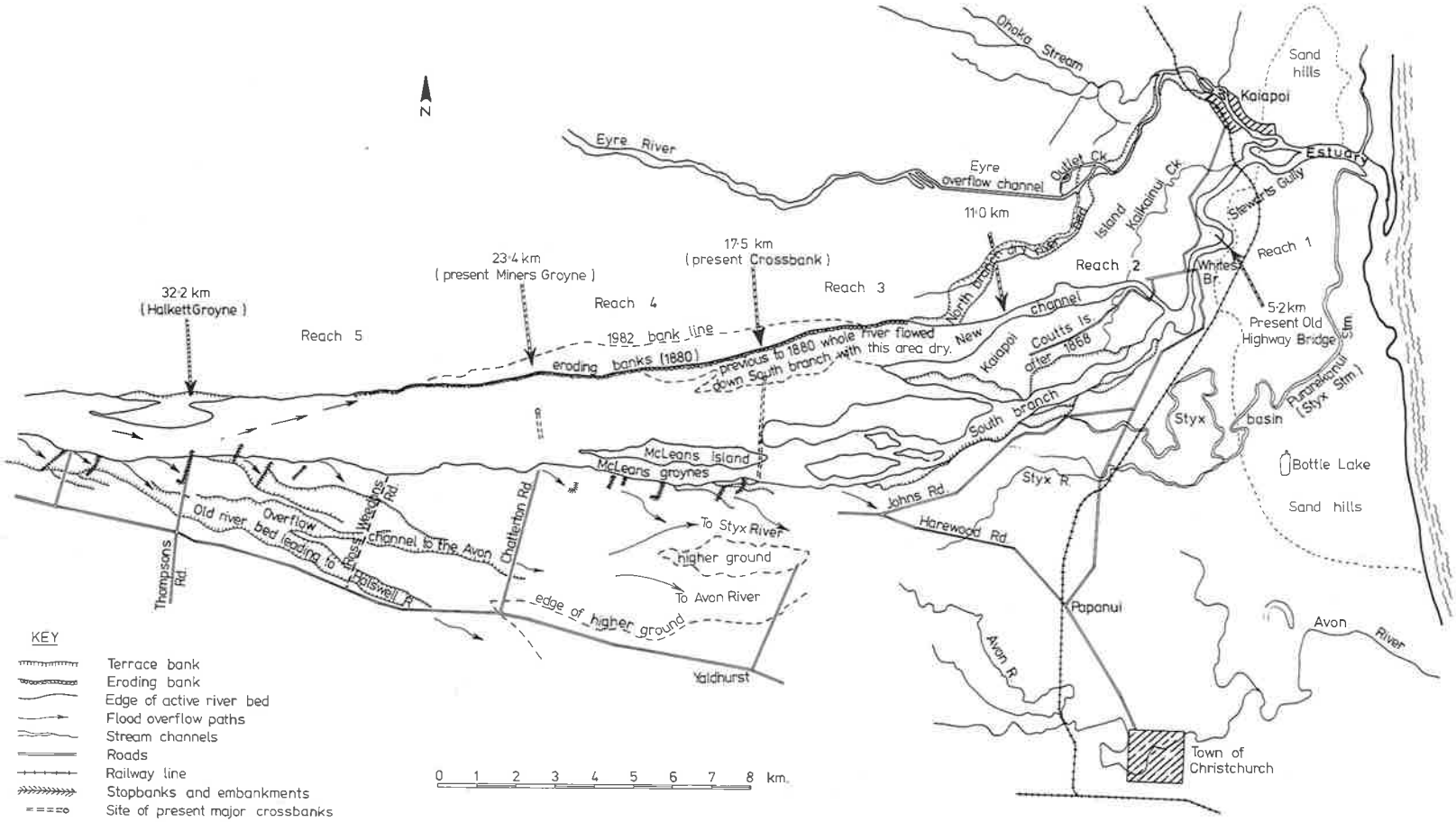


Figure 9: Waimakariri River control works: middle and lower reaches as in 1880.

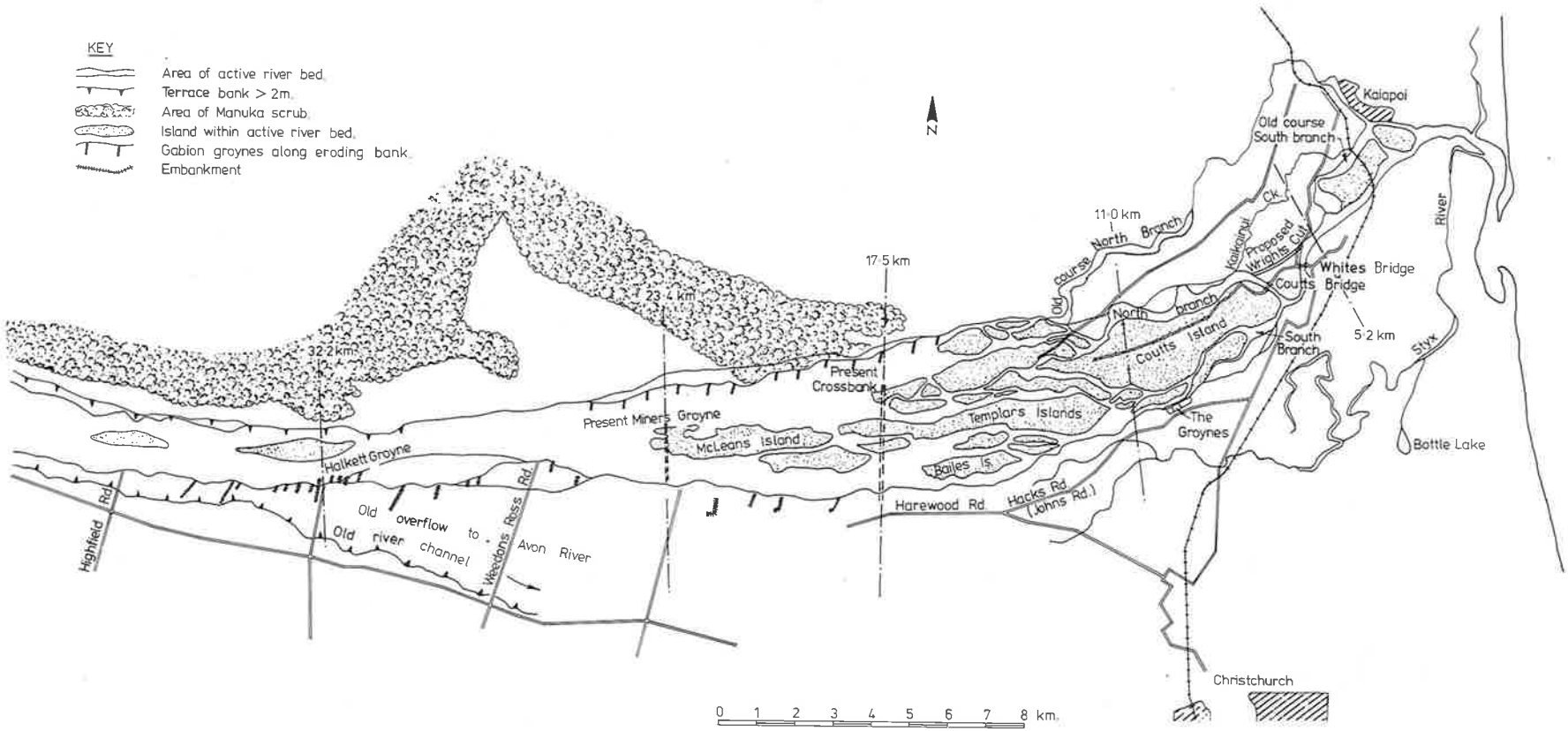


Figure 10: Waimakariri River control works: middle and lower reaches as in 1928.

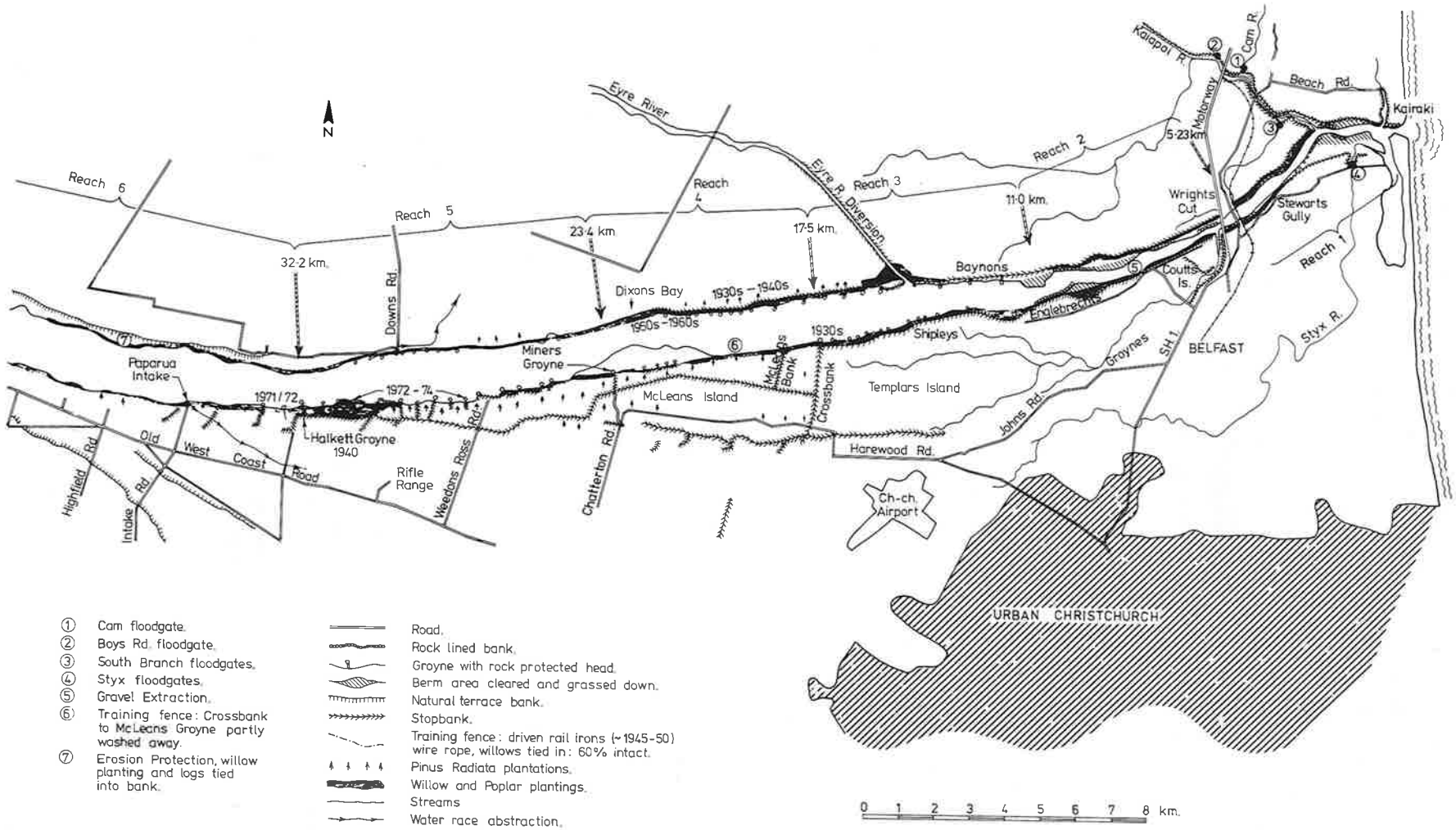


Figure 11: Waimakariri River control works: middle and lower reaches as in 1982.

Figure 12: Construction of the Crossbank, May 1932. (Christchurch Press)

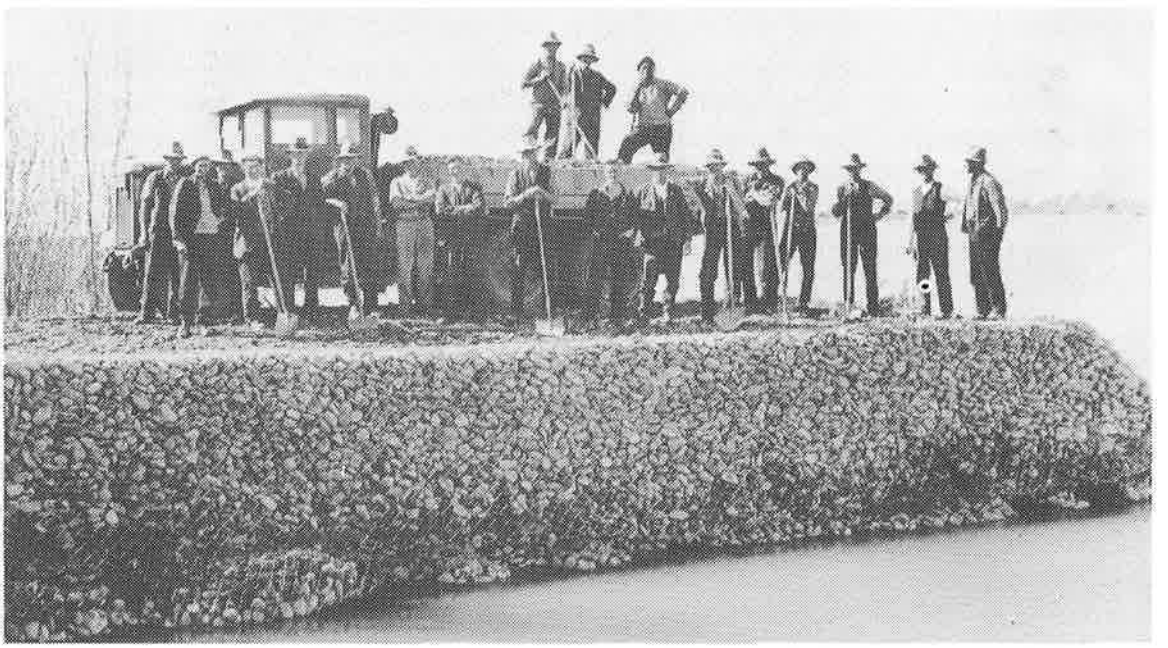


Figure 13: Example of a completed gabion groyne head constructed in the 1930's. (NCCB)

(1) Construction of the Crossbank in the early 1930's (Figure 12).

(2) Construction of the 720 m long Halkett Groyne in the early 1940's.

(3) Construction of Wrights Cut from 1928–1931, with a subsequent reduction in flooding on Coutts and Kaiapoi Islands.

(4) Formation of the present river mouth during the 1940 flood.

(5) A major programme of afforestation on 780 ha of Endowment Lands downstream from Courtenay on the south bank, from 1931 to 1939, under unemployment relief schemes.

(6) A major programme of gabion groyne construction carried out to limit further bank erosion on the north bank, mainly in reach 4 (Figure 13).

3.4 North Canterbury Catchment Board

In April 1946, the Waimakariri River Trust was dissolved and its responsibilities and assets, including the Endowment Lands granted by the Crown to the South Waimakariri River Board in October 1880, were transferred to the North Canterbury Catchment Board (NCCB). The 1970 Waimakariri River Improvement Amendment Act, section 3, extended the power given by the 1923 Act by conferring the power to "subdivide, improve, and develop all or any part of the land . . . vested in the Board". The Board resolved at a meeting

in November 1978, "to lease land for recreational purposes" (Norton, 1983, p. 14), subject to conditions of use defined by the Board and the relevant local authorities. An important emphasis in the conditions laid down by the Paparua and Eyre County Councils for the 838 ha of the McLeans Island Recreation Zone, is the requirement that "all development is in harmony with the natural character of the area" (Norton, 1983, p. 15).

The Board administers a public resource, allocating water and leasing land, in this way conferring certain rights to users for defined periods of time.

The Board's legal responsibilities under the water and soil conservation legislation inter alia are:

(1) "To minimise and prevent damage within its district by floods and by erosion, and to promote soil conservation" (Soil Conservation and Rivers Control Act 1941: Section 126).

(2) To promote the conservation and most beneficial uses of water (including multiple use) within its region, including the use of adjacent lands affected by flood waters. This involves the allocation of quantities of water above a "minimum flow" level to different water users (Water and Soil Conservation Act 1967: sections 20 and 21).

(3) To ensure that "adequate account is taken of the needs of primary and secondary industry, community water supplies, all forms of water-based recreation, fisheries, and wildlife habitats, and of the preservation and protection of the wild, scenic, and other natural characteristics of rivers, streams and lakes" (Water and Soil Conservation Amendment Act 1981: section 2).

Control of the Waimakariri River has been a major concern of the NCCB since its establishment.

Major floods in May 1950 (3090 m^3/s, RI 18 years) and December 1957 (3990 m^3, RI 65 years) broke the stopbanks in several places downstream from the Crossbank, causing widespread flooding of farmland, particularly around Coutts Island. Continuing aggradation in the lower reaches (reaches 2 and 3) caused serious concern and the existing control scheme was revised in 1960. Henderson (1960) noted that the aim of the 1930 scheme was essentially to train the river to pass floods and gravel out to sea without excessive channel aggradation, and concluded that the control works had partly achieved this aim. His conclusions were based on cross-section survey data from 1930 to 1955, which indicated that over 1.5 million m^3 of gravel were swept out to sea or at least downstream of the Old Railway Bridge. He recommended continuation of extensive bank protection works upstream of the Crossbank in reaches 4–7, without further restriction of the braided channel system, and development of a stable channel in reaches 1–3 which would be able to transport to the sea the water and sediment supplied to it from the upstream reaches. Gravel extraction was considered the probable long-term answer, with river training being a necessary continuing remedy.

The result of the investigations by Henderson and the Board staff was the Waimakariri River Improvement Scheme of 1960 (Reid and Dick, 1960), which had as its objectives ". . . to pass without overflow the design flood of 167,000 cusecs (4730 m^3/s) safely to the sea", and "to deal with the problem of aggradation in the lower reaches, as far as appears practicable and necessary at the present time".

The objectives of the current scheme remain the same, but the 1982 scheme review also emphasises the legal responsibilities of the Board as set out in the Waimakariri River Improvement Act 1923 (Reid and Poynter, 1982, pp. 1–2).

The main events of relevance to the control of the Waimakariri River during the period 1946–1982 were (Figure 11):

(1) The major flood of December 1957 followed by a period of 25 years with no floods having RI exceeding 12 years (Table 2).

(2) Extraction, mainly from reach 2, of 3.7 million m^3 of gravel between 1961 and 1968 for the construction of the Northern Motorway.

(3) Construction of the McLeans Island stopbank in 1968/69, which effectively cut off the ponding area upstream of the Crossbank.
(4) Construction of 5 major groynes upstream and downstream of Halkett Groyne from 1971 to 1974.
(5) Upgrading of stopbanks to the 1960 scheme design standards.
(6) Construction and maintenance of groynes for protection of the north bank, particularly in Dixons Bay (reach 4) and the Downs Road areas (reach 5).
(7) Removal of two constrictions in the design dominant flood channel (Henderson, 1960, pp. 44–46) in the lower reaches:
   (a) in the reach for 3 km downstream of Englebrechts (8–11 km), obstructing berm-lands and islands were removed to allow a more even design meander channel.
   (b) at Wrights Cut, which was constructed to reduce backwater effects and loss of flood capacity.
(8) Placement of rock rip-rap along the design dominant flood channel in reaches 1 to 3, which led to development of a gravel bed channel (compared with the pre-river control multiple channel system).

Figure 14 illustrates a typical cross-section in the lower reaches of the river, as developed by the 1960's.

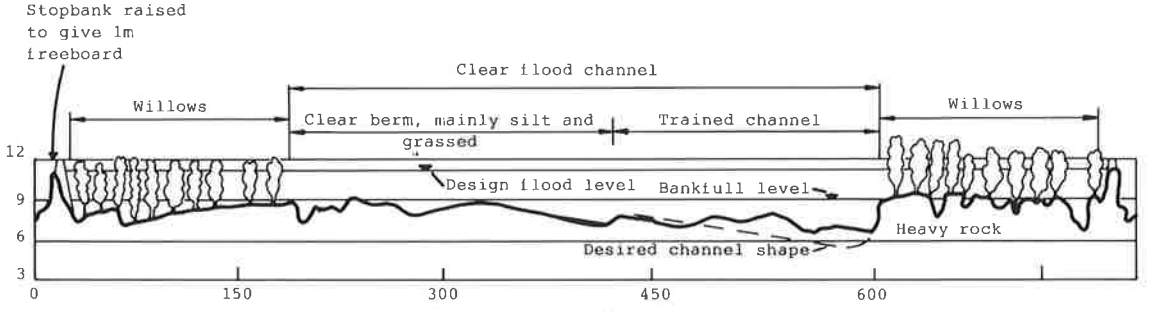


Figure 14: A typical cross-section on the Lower Waimakariri River (cross-section 8.45 km).

3.5 Future Works

The Waimakariri River Control Scheme (as described in the 1960 Scheme report and the 1976 Review by Dwyer and Poynter) is not complete. Work to date was reviewed in 1982 and works required to complete the scheme to the original design standards by 1987 have been submitted for approval (Reid and Poynter, 1982). It is beyond the scope of this study to discuss these proposals.

3.6 Type of Control Works

There have been two distinct stages in controlling the Waimakariri River. The first stage, lasting from 1840 to 1950, was predominantly labour intensive. It reached its peak during the depression of the 1930's when large gangs of men equipped with wheelbarrows, picks, shovels, and horses to pull the heavy equipment such as scoops or draglines, were employed on relief work constructing the control structures (Figures 12 and 13).

The main method used to control bank erosion and improve channel alignment in the wide braided reaches was the construction of gabion groynes at regular intervals along an eroding bank (Figure 15), followed by willow pole planting in the bays created between the groynes (Figure 16). The bays would rapidly fill with flood debris (initially gravels, then sands and silts), and eventually a new bank line would form along the line of the armoured ends of the groynes (Acheson, 1968; Furkert, 1915). Continued maintenance of these strong

A: during 1957 flood. (NCCB)

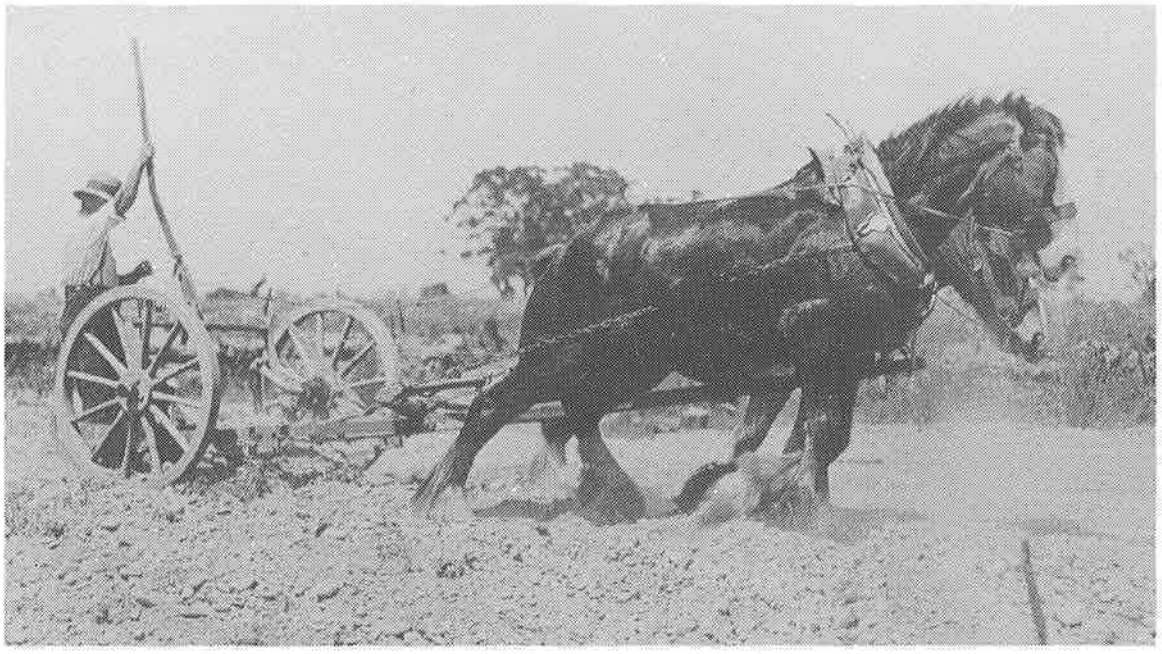
B: 1983 (R. Blakely, MWD)

Figure 15: Eroding bank after construction of protection works, north bank, Downs Road area.

points was essential to hold the new alignment until vigorous tree protection could bind the structure into the developing stabilised banks (Figure 17).

Piles (generally railway irons) were driven into riverbed with the aid of a mechanical pile driver and timber railings were wired along them creating a permeable barrier to floods. Willow trees and poles were also wired along the retard with the object of establishing a live barrier to floods. Sedimentation around these structures usually resulted in the effective blocking of overflow channels or the realignment of a length of eroding river bank (Figure 17). As with the gabion groynes, they also required a large input of labour in the first few years to maintain them.

Widespread afforestation, usually with *Pinus radiata*, of large areas of old riverbed and floodplain was also carried out, which often aided the sedimentation processes by increasing the bed roughness during floods, thereby lowering flow velocities and inducing siltation.



A: 1930's (NCCB)

16B: 1982 (R. Blakely, MWD)

Figure 16: Willow and poplar pole planting.

Figure 17: Established bank line along pile retard using willow trees (*Salix fragilis*). (R. Blakely, MWD)

Figure 18: Establishment of a new bank line along a retard using rock. (R. Blakely, MWD)

Since 1950, the methods of river control construction and maintenance have changed and, because labour costs have increased, the formerly labour intensive practices have been replaced by the greater use of mechanisation.

By the 1960's the Board's bank protection policy had changed in favour of using rock rip-rap carted by truck from the Halswell quarry, and more recently from Lyttelton (Figure 18). Large, durable volcanic rocks are dumped over the face of damaged gabion groyne heads and also used to line the outside bends of the design dominant flood channel in the lower reaches.

The motor scraper has replaced the pick, shovel and wheelbarrow for stopbank construction and gravel extraction, and other practices include the use of a bulldozer and tyne for planting willows, poplars and pines (Figure 16B) and chemical sprays for weed control and the removal of unwanted trees in floodways.

Control work on the Waimakariri River is now carried out primarily by contractors with heavy machinery, and two gangs of Board staff engaged mainly on maintenance of existing works and planting of bermland and riverbed areas. Today, the Board's role is increasingly administrative, in contrast to its more active involvement in major scheme construction from 1930 to 1970.

3.7 Cost of Works

The analysis of costs is restricted to those incurred on the river and its riparian lands as shown in Figure 11, although benefits to the whole floodplain are considered below.

The Economic report contained in the Waimakariri River Control Scheme Report of 1960 (Reid and Dick, 1960) lists expenditure and revenue for the period 1924 to 1959. It includes

Table 3: Waimakariri River Control Scheme: expenditure (×$1000 in 1982 values) on new river control works, maintenance, and flood damage (1959-81) (Data from NCCB accounts).

	Reach							
Year[1]	1	2	3	4	5	6	7	Total
1960	94.3	42.7	338.2	226.1	226.1	33.8	33.8	995.0
1961	287.4	200.1	278.4	144.4	144.4	3.5	3.5	1,052.7
1962	358.7	370.6	102.0	90.1	125.8	22.1	0.0	1,069.0
1963	840.0	529.2	115.9	35.3	73.9	0.0	0.0	1,594.3
1964	547.8	149.2	187.0	73.8	385.4	23.0	23.0	1,389.2
1965	570.0	171.8	319.2	27.4	152.0	12.2	12.2	1,264.8
1966	834.7	23.7	145.0	82.9	259.0	7.4	7.4	1,360.1
1967	390.5	244.2	59.6	191.7	116.4	18.5	18.5	1,039.4
1968	184.2	242.9	131.8	405.0	69.7	25.5	25.5	1,084.6
1969	316.9	197.8	78.1	263.3	73.1	13.2	10.7	953.1
1970	240.1	173.5	112.7	85.6	76.1	27.7	11.2	726.9
1971	352.0	98.0	88.0	23.5	59.0	22.5	48.0	691.0
	(75.5)			(0.5)	(42.5)			(118.5)
1972	433.4	119.3	52.7	30.6	118.8	67.5	20.3	842.6
		(8.1)			(22.1)			(30.2)
1973	157.0	94.6	135.5	15.9	72.2	25.8	22.8	523.8
					(7.7)			(7.7)
1974	173.6	56.2	54.2	56.9	134.6	46.8	36.3	558.4
1975	64.6	21.4	154.9	44.5	166.4	38.1	17.0	506.9
				(25.9)				(25.9)
1976	100.6	91.8	56.9	18.5	33.0	40.0	15.3	355.6
				(1.6)				(1.6)
1977	70.4	62.8	160.1	31.3	64.6	40.7	20.7	450.6
				(2.3)				(2.3)
1978	47.8	85.4	143.2	50.6	27.2	69.2	15.6	439.0
1979	66.8	147.4	186.0	15.3	13.3	29.1	20.6	478.5
1980	42.3	129.6	236.4	13.6	62.1	54.9	15.6	554.5
			(2.0)		(37.2)	(22.1)		(61.3)
1981	166.7	123.4	127.2	38.4	56.8	70.6	89.9	673.0
			(34.8)		(23.5)	(37.3)	(5.9)	(101.5)
Totals[2]	6330.8	3375.6	3263.0	1964.7	2509.9	692.1	467.9	18,604.0
	(75.5)	(8.1)	(36.8)	(30.3)	(133.0)	(59.4)	(5.9)	(349.0)
Relative Ratios	0.34	0.18	0.17	0.11	0.135	0.04	0.025	1.00

Notes:

[1]The year indicated refers to the time period from 1 April of the previous year to 31 March of that year, e.g., 1960 represents the period 1959/60.

[2]For each year and in each reach the upper figure is the total expenditure and the lower bracketed figure is that part of the total resulting from flood damage. Where no lower figure is indicated, flood damage may be treated as negligible.

the costs of the construction of new river control works and their maintenance, development and maintenance of reserve lands, administration and engineering, loan interest and repayments and unemployment relief schemes. Based on these data and earlier NCCB records, E. B. Dalmer (Reid and Dick, 1960) estimated the total expenditure on control works and reserve development up to 1960 to have been 5 million pounds (1960 value). Using the MWD cost construction index (CCI) ratio of 8.7 (ie, 1982 CCI divided by 1960 CCI), Palmer's total expenditure figure converts to $87 million (1982 value). In arriving at this total no deductions have been made for revenue from land rentals or timber sales because these data were not available in a form which could be converted to 1982 values. Land rentals totalled £124,000 over the period 1924 to 1959, while timber sales are assumed to have been negligible because they are not listed in the receipts.

Since 1959, expenditure on the river control scheme (1982 values) has totalled nearly $19 million (Table 3). One third was spent in reach 1, one sixth in each of reaches 2 and 3, and the bulk of the remainder in reaches 4 and 5. Expenditure was greatest in the years following preparation of the 1960 scheme, up to more than $1.5 million in 1963, and declining to less than $0.5 million per year in the late 1970's. Flood damage repair costs have ranged up to $118,000.

Table 4 itemises expenditure on new works, maintenance and flood damage repair, development and maintenance of reserves, and revenue from reserves. The income from the 6168 ha of reserves (Figure 19) has exceeded expenditure on them by nearly $1.4 million since 1960, and has been deducted to compute net expenditure on the control scheme (Table 5). Since 1857, over $106 million (1982 values) has been spent on the Waimakariri River control scheme, mainly in the lower reaches. However, it should be noted that more efficient technology now available for stopbank and groyne construction (scrapers and bulldozers) means that this 1982 cost for the total works would over-estimate the cost to build the same scheme in 1982, since labour costs would form a much smaller part of the total.

Table 4: Waimakariri River Control Scheme: itemised expenditure and revenue ($1000 in 1982 values) on river control works and reserves, 1959–81

	River Control					Reserves				
Year	New river control works	Maintenance	Flood damage	Administration and engineering	Total expenditure relating to river control	Development and maintenance	Timber sales revenue	Land rental revenue	Net revenue	Net expenditure river control and reserves
1959/60	873.0	122.0	-	126.0	1,121.0	47.5	0.0	98.8	51.3	1,069.7
1960/61	935.7	117.0	-	122.0	1,174.7	52.1	7.0	97.4	52.3	1,122.4
1961/62	982.0	87.0	-	107.0	1,176.0	86.1	0.0	96.4	10.3	1,165.7
1962/63	1,506.3	88.0	-	134.0	1,728.3	60.5	0.0	104.8	44.3	1,684.0
1963/64	1,374.2	15.0	-	125.0	1,514.2	75.4	0.0	108.4	33.0	1,481.2
1964/65	1,212.8	52.0	-	174.0	1,438.8	42.3	0.0	105.2	62.9	1,375.9
1965/66	1,308.1	52.0	-	128.0	1,488.1	63.3	0.0	119.1	55.8	1,432.3
1966/67	840.4	199.0	-	166.0	1,205.4	56.2	3.1	119.5	66.4	1,139.0
1967/68	927.2	154.0	-	203.0	1,284.2	64.2	56.4	113.5	105.7	1,178.5
1968/69	813.1	140.0	-	149.0	1,102.1	146.1	76.1	104.4	34.4	1,067.7
1969/70	618.9	108.0	-	169.0	895.9	88.0	0.0	105.2	17.2	878.7
1970/71	437.5	135.0	118.5	147.0	838.0	205.1	102.8	104.3	2.0	836.0
1971/72	666.4	146.0	30.2	120.0	962.6	147.2	143.5	104.5	100.8	861.8
1972/73	416.1	100.0	7.7	132.0	655.8	142.7	69.9	118.8	46.0	609.8
1973/74	460.4	98.0	-	120.0	678.4	183.0	215.8	141.4	174.2	504.2
1974/75	361.0	120.0	25.9	64.0	570.9	213.9	225.2	133.2	144.5	426.4
1975/76	250.0	104.0	1.6	48.0	403.6	350.7	326.9	110.7	86.9	316.7
1976/77	351.3	97.0	2.3	58.0	508.6	1,009.8	918.8	101.0	10.0	498.6
1977/78	335.0	104.0	-	58.0	497.0	696.2	611.9	118.1	33.8	463.2
1978/79	336.5	112.0	-	37.0	515.5	458.3	429.2	110.9	81.8	433.7
1979/80	340.2	153.0	61.3	44.0	598.5	228.9	188.2	106.1	65.4	630.6
1980/81	461.5	110.0	101.5	42.0	715.0	208.4	184.8	108.0	84.4	731.6
TOTALS	15,837.6	2,413.0	349.0	2,473.0	21,072.6	4,625.9	3,559.6	2,429.7	1,363.4	19,709.2

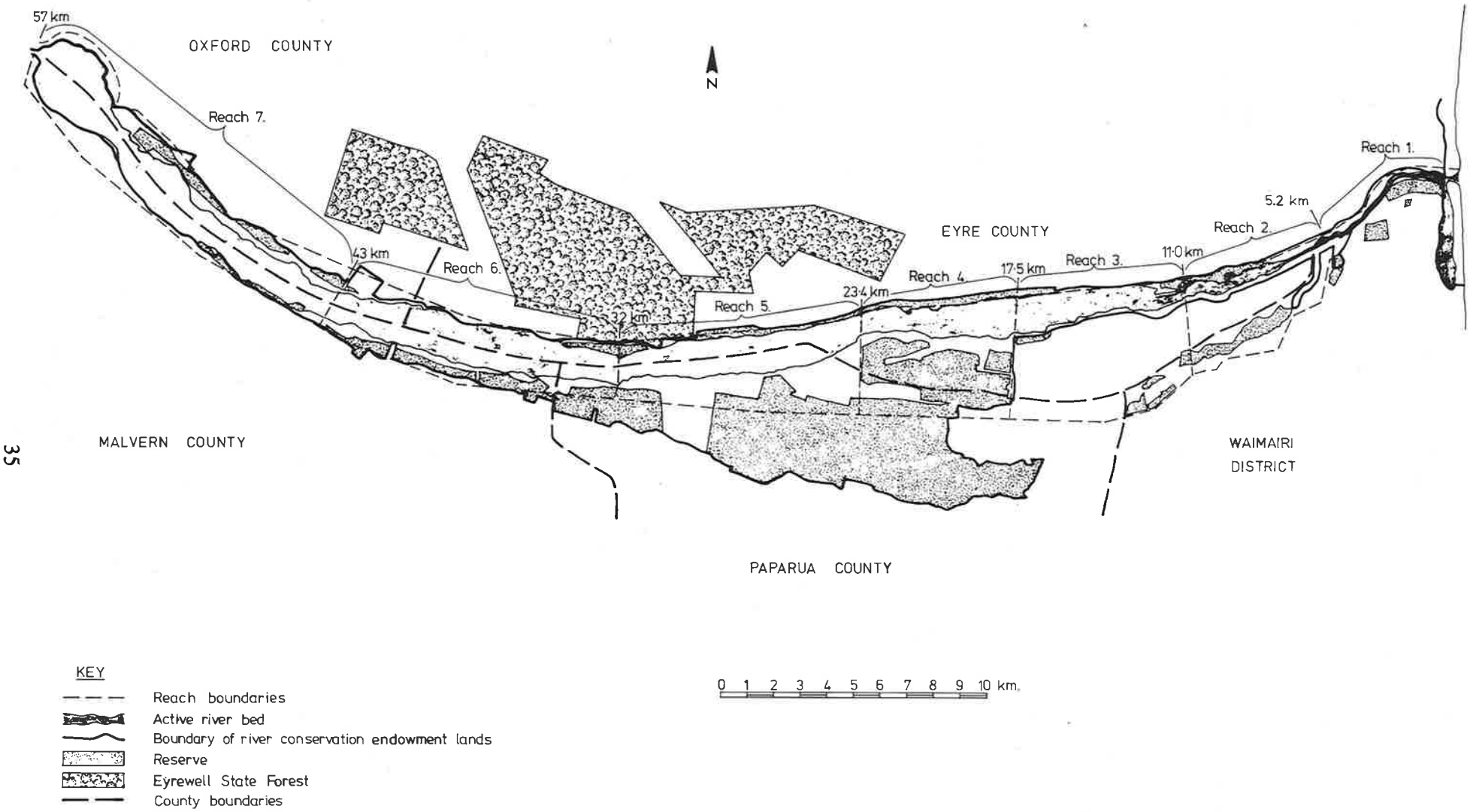


Figure 19: Waimakariri River reserve and riparian lands, showing county and borough boundaries, 1982.

Table 5: Waimakariri River Control Scheme: expenditure (x$1000 in 1982 values)[1] on river control, flood damage, maintenance and reserves, 1857–1981

Type of Expenditure	Reach							Total
	1	2	3	4	5	6	7	
River control including maintenance and flood damage[2]	6,331	3,376	3,263	1,965	2,510	692	468	18,604
Admin. and engineering[3]	840	445	420	272	334	99	62	2,473
Reserves[4] (Income)	−32	−59	−63	−578	−367	−163	−101	−1,363
TOTAL, 1959–1981	7,138	3,762	3,620	1,659	2,477	628	429	19,714
Estimated[5] expenditure 1857–1959	8,700	17,400	17,400	21,700	17,400	3,500	900	87,000
ESTIMATED TOTAL, 1857–1981	15,800	21,200	21,000	23,400	19,900	4,100	1,300	106,700

Notes:

[1]Expenditure adjusted to 1982 values.

[2]Data from Table 3.

[3]Data from Table 4. Total expenditure divided between reaches in proportion to expenditure on river control and maintenance work.

[4]Development, maintenance and administration expenditure on Waimakariri reserves minus revenue from timber sales and land rental as listed in Table 4. Net income divided between reaches in proportion to the area of reserves in each.

[5]Based on analysis of annual accounts, Appendix 1 of Economic Report of 1960 Scheme Report (Reid and Dick, 1960), and discussions with NCCB staff.

4 Changes in River Behaviour

The primary objective of the Waimakariri River control scheme has been to create a flood channel which is able to convey to the sea all floods up to the design flood with an RI of 100 years. A necessary subsidiary objective has been to limit aggradation in the lower reaches of the river.

This section examines changes in channel morphology, flood frequency, sedimentation, and hydraulic characteristics, in order to assess the impact of the river control works on river behaviour.

4.1 Measurements

The primary source of data is river cross-section surveys carried out by the NCCB and its predecessors (Henderson, 1960; Reid and Dick, 1960; Reid and Poynter, 1982). Thirty-six of these cross-sections between the Lower Gorge and the sea were selected at a maximum spacing of two active channel widths. Each has been surveyed by River Trust and NCCB staff on at least three occasions: 1929/32, 1955/58, and 1974/78. (It should be noted that a complete survey of all the regularly surveyed cross-sections takes up to 5 years). From these records, the following variables were quantified for each cross-section.

(1) **Bankfull channel cross-sectional area (A)**, the area of the channel below the level of the floodplain and vegetated islands. However, in reaches confined by stopbanks and other structures, aggradation of the berms may have raised this level above that of the natural surrounding floodplain.

(2) **Cross-sectional area at the maximum design flood**, the area of the channel below the level of the stopbanks, allowing for a freeboard of 0.9 m.

(3) **Bankfull channel width (Wb)**, the width across the active bed at the height of the floodplain, excluding the width of vegetated islands.

(4) **Mean bed level**, computed by dividing bankfull channel cross-sectional area by bankfull channel width to give mean bankfull depth which was then subtracted from the floodplain elevation.

(5) **Effective width (We),** the width of riverbed occupied by the 100 year design flood with a value of manning "n" greater than 0.05.

(6) **Channel width at the maximum design flood,** the total width across the channel at a level 0.9 m below the crest of the stopbanks.

(7) **Bankfull wetted perimeter,** the length of the riverbed in contact with water below the level of the floodplain, including the banks of islands, but excluding their top surfaces.

(8) **Wetted perimeter at the maximum design flood,** the length of the riverbed, floodplain, and islands in contact with water below the level of the maximum design flood, 0.9 m below the stopbank crest. Variables (1) to (8) were measured using a Hewlett -Packard digitiser, except for (5) effective width.

(9) **Bed slope (S),** computed as the average of the slopes between each cross-section and the ones upstream and downstream of it. The mean bed levels of the cross-sections were used to compute bed slope and to give mean depth. Water surface and energy slopes are assumed to be equal to bed slope.

(10) **Manning roughness factor "n"** was estimated for each homogeneous sub-section, based on field work, interpretation of aerial photographs and NCCB map records, and backwater calculation from flood profiles using the Manning equation (data supplied by T. Boyle, Design Engineer, NCCB). Typical values are listed in Table 6; they have been verified with values measured in other gravel bed rivers (Chow, 1959; Schnackenberg, 1951).

(11) **Channel capacity,** the uniform flow discharge that would fill the channel up to bankfull level (bankfull channel capacity) or up to a level of 0.9 m below the stopbank crest) maximum design flood capacity). It was computed by applying the Manning

Table 6: Typical values of Manning's Roughness Coefficient for the Waimakariri River

Bed feature	Manning's Roughness Value (n)
Active riverbed, predominantly gravels with small areas of sand and silt	0.025
Active riverbed, mainly gravels, with small areas of cobbles	0.030
Bermland with rough grasslands and pockets of low scrub (gorse and broom)	0.050
Bermland with rough grasslands and areas of dense scrub	0.06-0.07
Forested berms, mainly dense willow and poplar	0.125

equation to subsections having different values of the Manning roughness coefficient, and then summing the individual values. Above reach 2, bed width is approximately equal to wetted perimeter, and discharge, Q, was computed using a modified form of the Manning equation:

$$Q = A^{1.66} S^{0.5} W^{-0.66} n^{-1}$$

Several assumptions underlying the Manning equation may have been violated:

(i) Uniform flow requires a constant discharge through a reach of uniform width, slope and bed roughness. Although each cross-section is different, changes between successive sections are generally small (i.e., width variation 10%, slope variation 5%).

(ii) Bankfull flow conditions in the Waimakariri River can occur during a period of several days of high flow caused by snow melt associated with north-westerly rains. Under such conditions, water surface slope is similar to bed slope. This condition is not likely to be true for larger floods, when water levels rise and fall rapidly over a period of several hours. However, other factors such as changing bed roughness associated with sedimentation or scour of the channel itself may have a more important influence on flow under these conditions. Moreover, discharge is proportional to the square root of slope, and is therefore relatively insensitive to small changes in slope.

(iii) Definition of the bankfull channel cross-sectional area is difficult, especially in the most unstable braided reach upstream of the Crossbank (reach 4), where there is a marked fall from the north bank towards the south bank (the direction of the Old South Branch channel system). Because of the presence of major groynes blocking flood paths to the south, flows within the bays between groynes or upstream of crossbanks have not been included in either "bankfull" or "design flood" calculations.

(iv) In reach 1, below the Old Highway Bridge (5.2 km), the tidal influence creates backwater effects which cannot be modelled using the Manning's formula. This reach is therefore excluded from subsequent hydraulic calculations.

(12) **Stream power** is the rate of energy expenditure per unit width of channel (Leopold *et al.*, 1964, p. 178) and is computed using the equation:

$$\varpi = \gamma \, Q.S./W$$

Where ϖ is in Watts per square metre of riverbed occupied by the flow, Q is the discharge being considered, S is the bed slope through a section of river, W is the width of the flow relevant to the discharge under consideration, and γ is the unit weight of water. Stream power was computed for each cross-section at bankfull flow (Qb) and at the 100 year design flood (Qm), using bankfull channel width (Wb) and effective width (We), respectively.

4.2 Results

Bankfull channel capacity (based on the measured bankfull channel cross-sectional area) was calculated for each cross-section at each of the three survey dates. It varies widely between cross-sections, and with time at each cross-section (Figure 20). In both the surveys illustrated in Figure 20, a capacity of 400 m^3/s is estimated at 19.93 km, ranging up to 5000 m^3/s at 45.06—km in 1929–32. Trends are more readily seen by computing average bankfull channel capacities for each homogeneous reach (Figure 21). Mean bankfull channel capacity was lowest at all dates in reach 4—approximately 1000 m^3/s—except for a value of 470 m^3/s in reach 2 in 1929. Reach 2 showed the greatest change in bankfull channel capacity over time, with a 250% increase from 470 to 1630 m^3/s between 1929–32 and 1974–78. In reach 3, however, there was a 54% decrease over the same period, from 2070 to 950 m^3/s. Mean bankfull channel capacity showed no progressive trend in reaches 4 and 6 over this period; it tended to increase in reach 5, and declined markedly in reach 7, particularly during the period 1932–57.

In 1929–32, which may be taken as representing conditions in the largely unmodified river, there is a clear trend for mean bankfull capacity to decline downstream; by 1974–78 this trend had become weaker, but less as a result of any increase in capacity in the lower reaches than of a decrease in capacity in reach 7.

Maximum design flood capacity This was estimated for all cross-sections between the Old Highway Bridge (beyond the influence of the sea) and Halkett Groyne (above which there are no continuous stopbanks). All cross-sections are able to convey the present 100 year flood of 4300 m^3/s without over-topping of the stopbanks, except in the vicinity of 12.47 km (3740 m^3/s) and 19.93 km (3890 m^3/s). This assumes banks do not fail by undercutting, seepage or shear.

Flood frequency The RI of bankfull flow in 1974–78 ranged from 1.0 to 4.8 years, except for cross-section 29.4 km (31.5 years) (Figure 22). Variations in the average RI of bankfull flow for each reach (Figure 23) mirror variations in bankfull flow itself (Figure 21). Most significant is the decline in average RI in reach 3, from approximately 4 years in 1929 to approximately 1.1 years in 1978—the lowest of any reach for this survey period. Also apparent is the constancy of RI at about 1.3 years in reach 4, and the progressive channel enlargement in reaches 2 and 5 which can now convey larger bankfull flows than in 1929. Reach 7 bankfull capacity is now more frequently surpassed than in 1929, although the average RI has remained close to 2 years since 1955.

At two cross-sections the stopbanks are unable to contain a flood with an RI less than 100 years; the maximum flood (assuming 0.9 m freeboard) at 12.47 km has an RI of 45 years, and at 19.93 km of 56 years. Only one other cross-section, 13.28 km, could not convey a maximum flood with an RI less than 250 years (Figure 22).

River control works to date have not generally increased mean bankfull channel capacities or the RI of bankfull flow (Figures 21, 23), but they have increased the RI of flood overflows that cause damage beyond the floodway, from approximately 5 years before about 1860 to about 50 years in 1982 (Reid and Poynter 1982). Before 1930, floods overflowed the south bank every 2–5 years on average. Between 1930 and 1960 floods up to 2750 m^3/s (RI of 10 years) were contained by the control works, with floods greater than 3000 m^3/s breaking out in 1936, 1940, 1950 and 1957. There have been no flows with an RI greater than 12 years since the 1957 flood, which had a peak discharge of 3990 m^3/s (RI = 65 years).

Stream power At bankfull flow, stream power tends to decrease in the downstream direction at all survey dates (Figure 24), primarily in response to the downstream decrease in bankfull capacity in reach 4 and a combination of this and decreasing slope in reaches 3 and 2 (Figures 20 and 30). Mean bankfull stream power remained approximately constant in reaches 4 to 7 at all dates. It declined from 140 to 41 W/m^2 in reach 3 from 1929–32 to 1974–78, and increased from 29 to 72 W/m^2 in reach 2 during the same period (Figure 25).

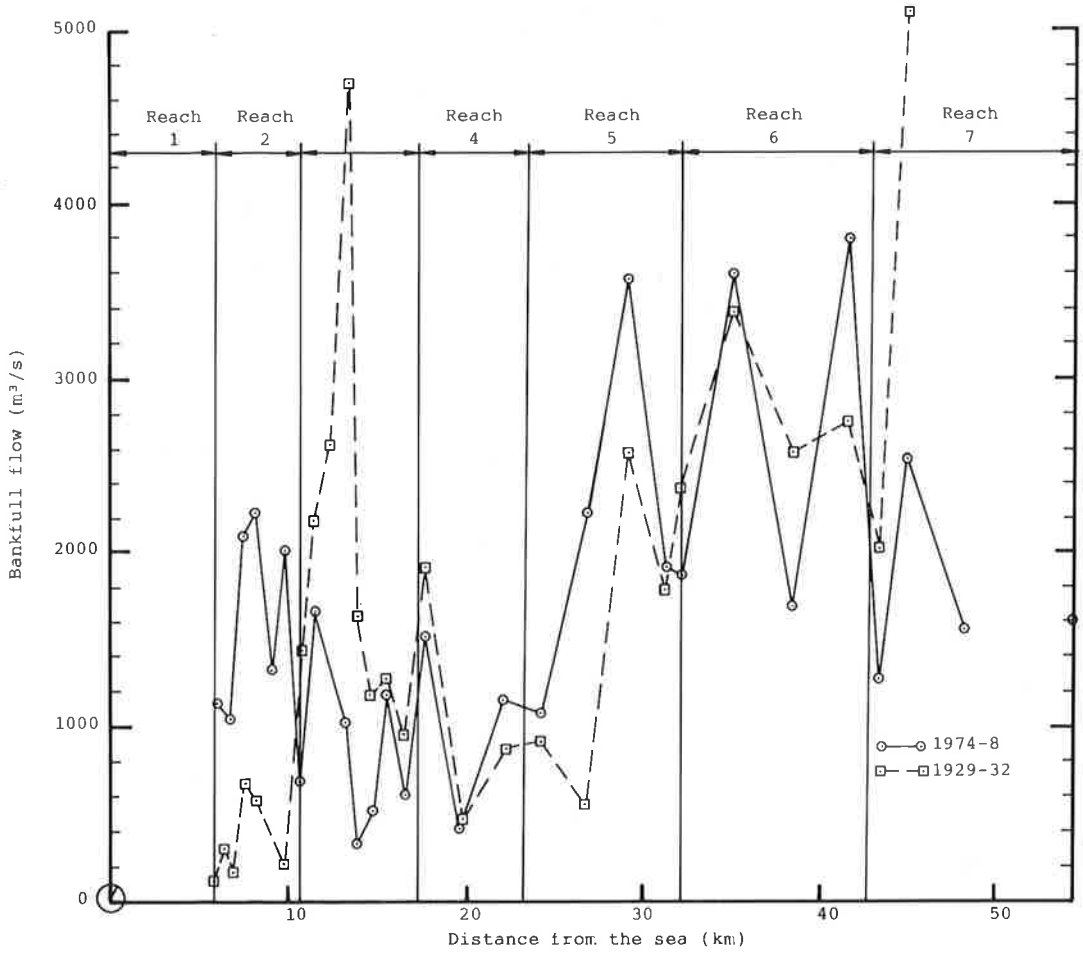


Figure 20: Bankfull channel capacity in the Lower Waimakariri River.

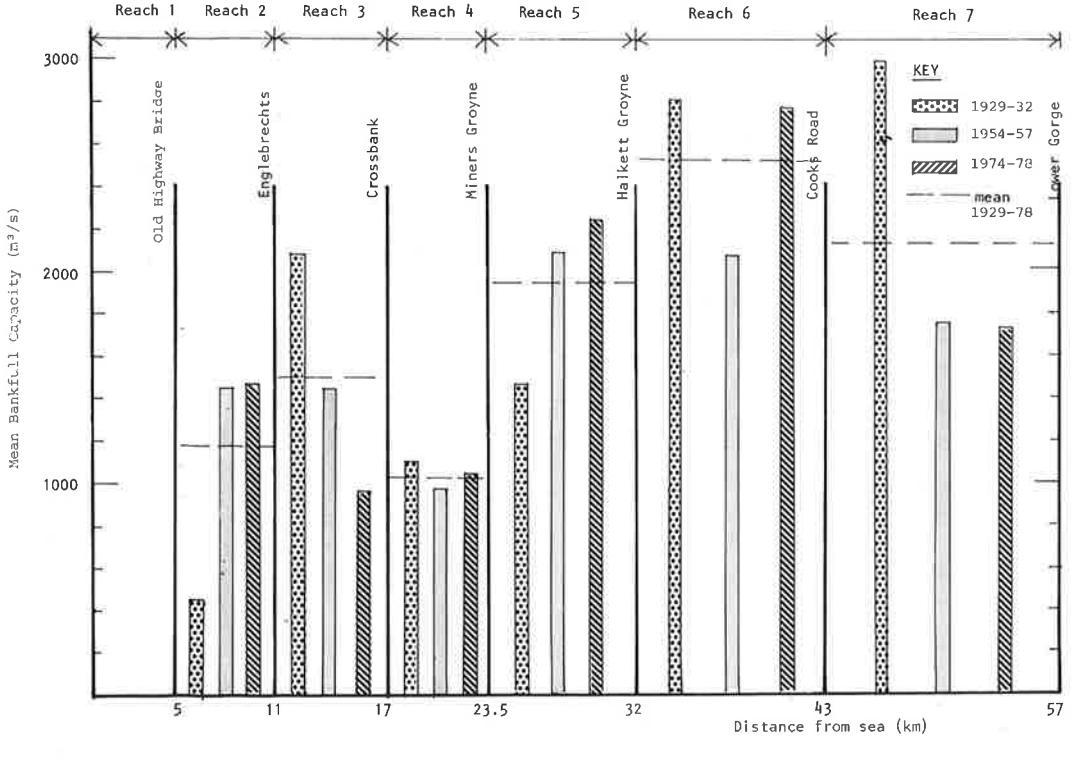


Figure 21: Mean estimated bankfull capacity for the Waimakariri River: 1929–1978. (Data: NCCB)

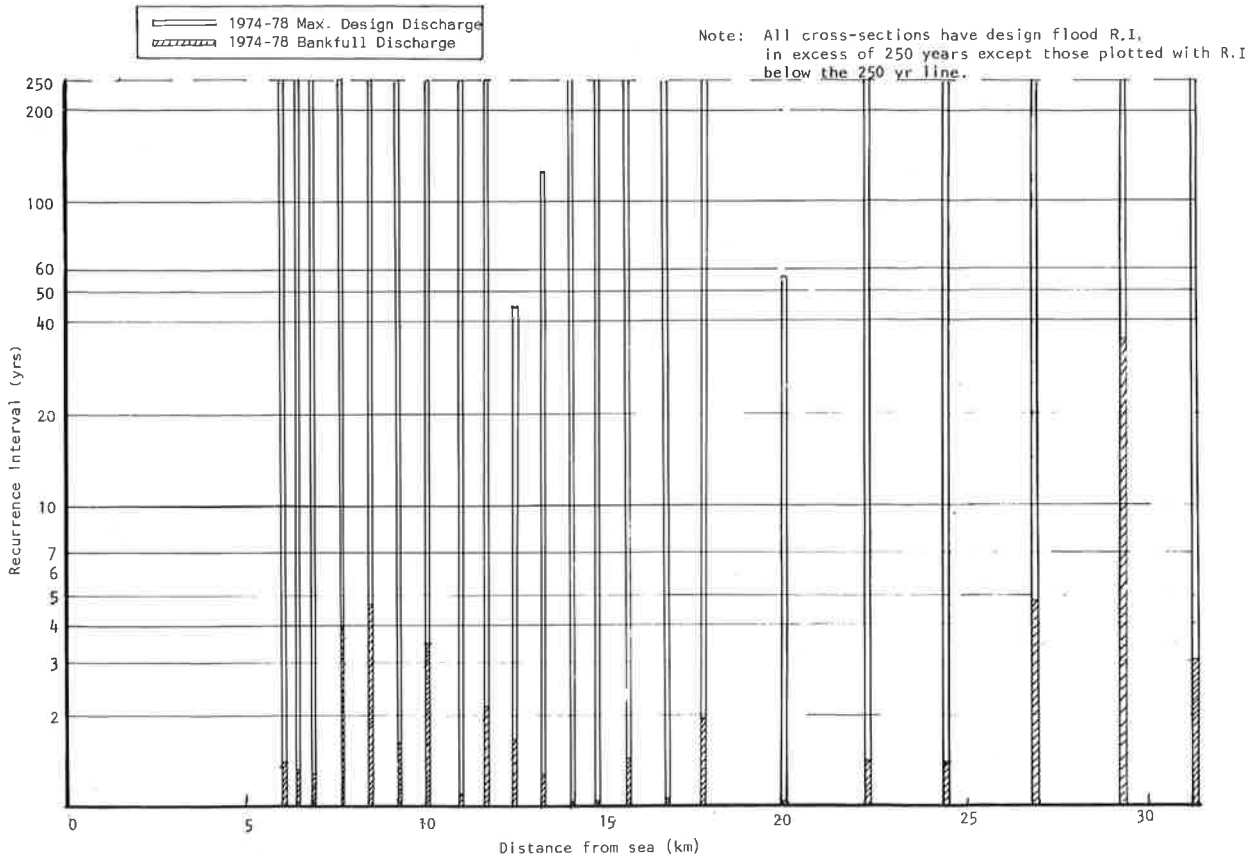


Figure 22: Waimakariri River estimated flood recurrence interval for selected cross-sections: 1974–78.

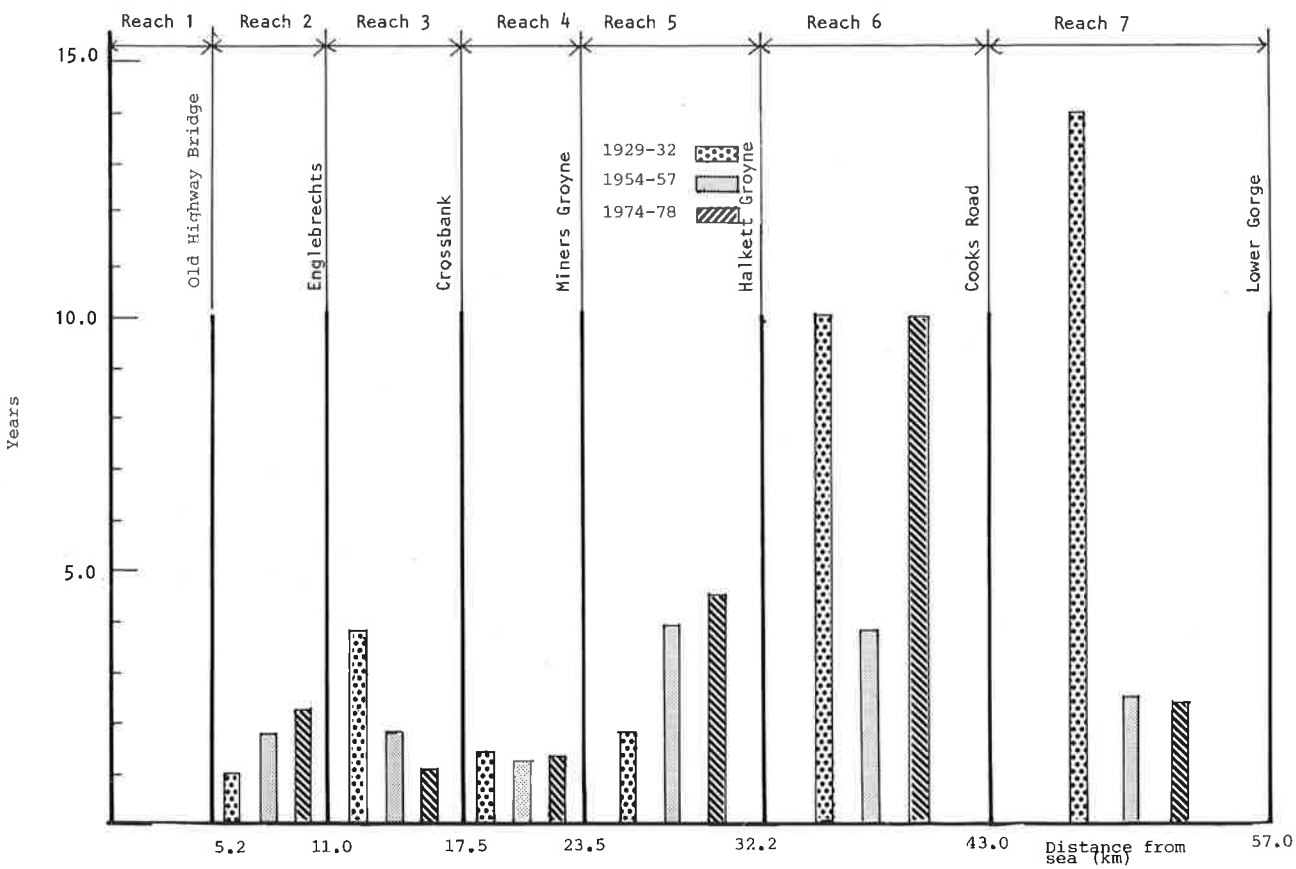


Figure 23: Waimakariri River mean estimated bankfull flow recurrence interval. 1929–1978.

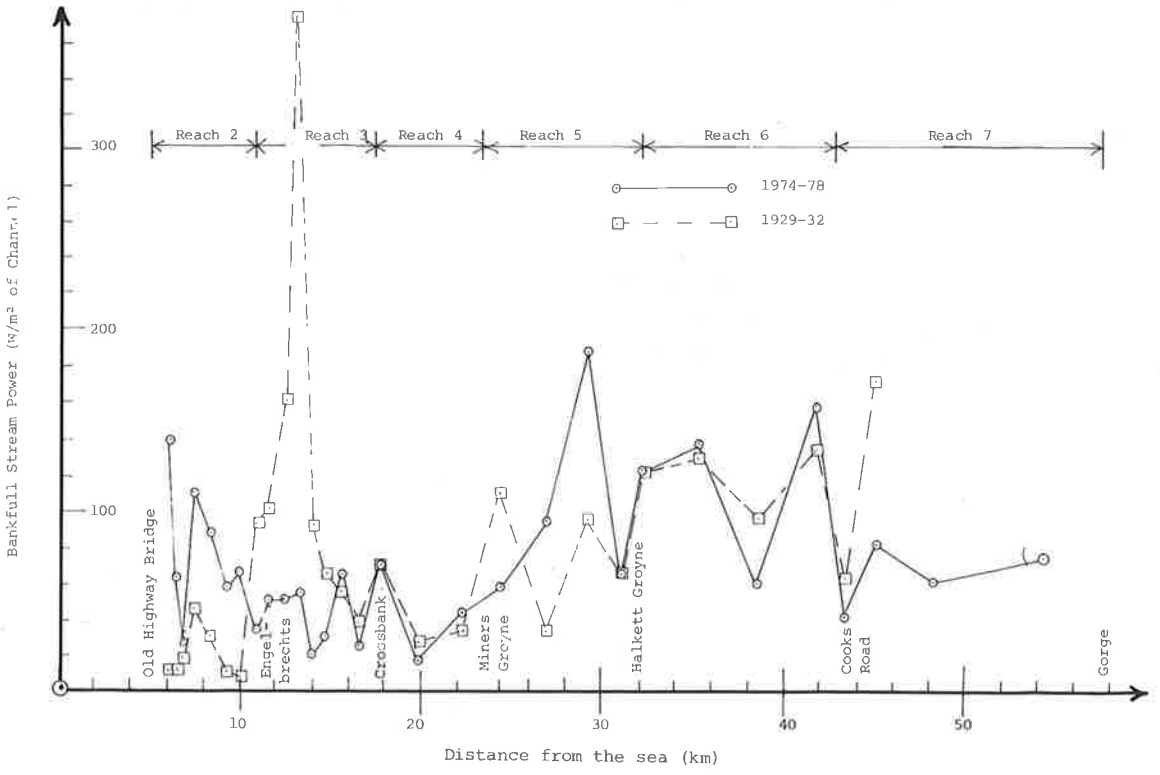


Figure 24: Bankfull stream power at each cross-section: 1929–1978.

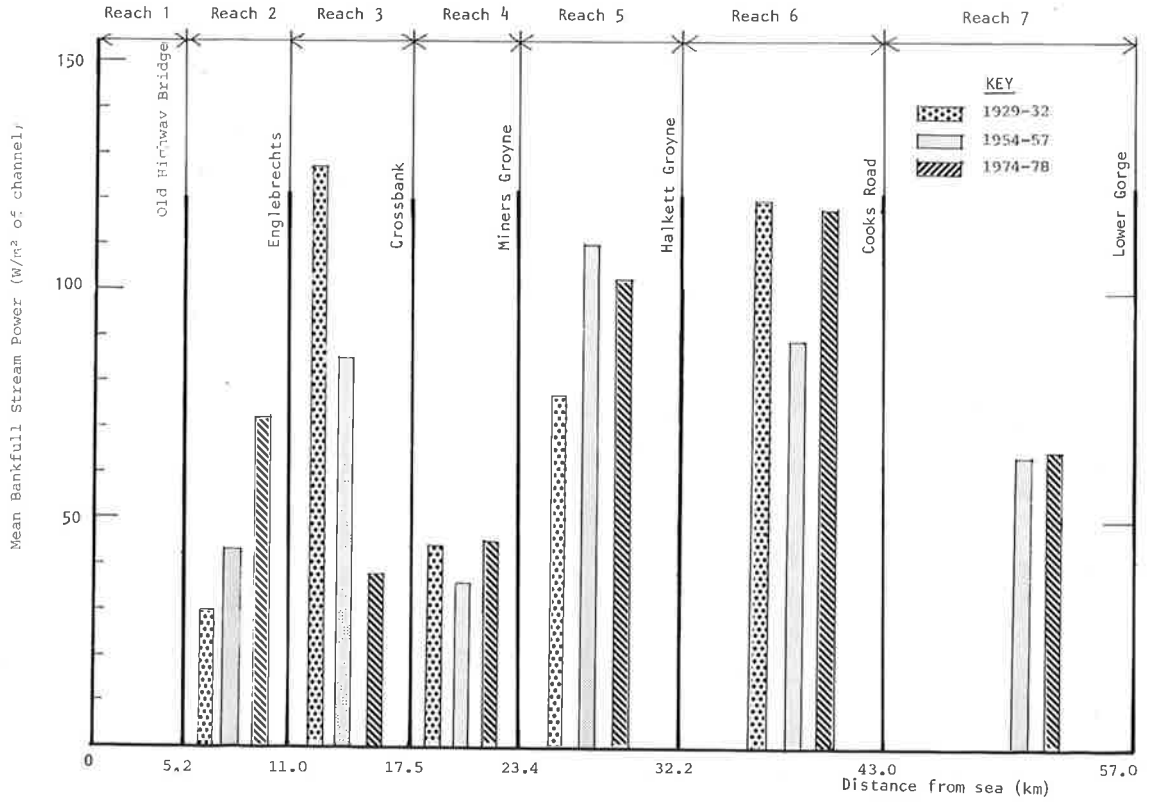


Figure 25: Mean bankfull stream power within each reach: 1929–1978. (Data: see Appendix 1)

The unusually high value of stream power at 13.27 km in 1929–32 (Figure 24) is related to a local decrease in bankfull channel width from 755 m at 14.08 km to 517 m at 13.27 km, and then an increase to 676 m at 11.67 km. The low values in 1929–32 in reach 2 are because Wrights Cut had only recently been completed, and its bankfull flow capacity was still small. By 1974–78, its bankfull capacity had increased to 1450 m^3/s and mean bankfull stream power in the reach had increased from 29 to 72 W/m^3. The low bankfull stream power values in reach 3 are associated with the low bankfull capacities measured therein (Figure 20).

Stream power at the 100 year design flood The 100 year flood is constant at 4300 m^3/s throughout reaches 1–7 (although at some locations the stopbanks are at present unable to contain such a discharge) and the bed slope is constant over much of the Waimakariri River below the Lower Gorge as far as the Crossbank (Figure 30). However, the effective width decreases from about 1300 to 400 m from reach 4 to reach 2, with local constrictions at Halkett Groyne (32 km) and Engelbrechts (11 km) (Figure 26). Maximum stream power occurs at these two locations, with values of 300 and 400 W/m^2, respectively, with a general tendency for stream power to be greatest in reach 3 (Figure 26). The minimum value of 86 W/m^2 occurs at the head of Wrights Cut (6.86 km), where the local bed slope is only 0.0008, and is roughly half of the slope at the cross-sections upstream and downstream.

Channel pattern changes The overall channel pattern has changed markedly from 1927 to 1982 (Figure 27). Active bed width (equivalent to the bankfull channel width) and the number of low flow channels were measured on aerial photographs taken in 1932, 1957, 1976, and 1982. Discharge was less than 100 m^3/s in each survey; the active bed width measured on aerial photographs is approximately equal to the bankfull width measured on cross-section drawings.

Present active bed width declines gradually from about 1100 m in reach 7 to about 700–800 m in reach 3, with reaches 1 and 2 being markedly narrower—only 250 m (Figure 28). In 1932, mean active bed width declined by 880 m from 1360 m in reach 3 to 480 m in reach 2, so that the present reduction in width of about 280 m is markedly less severe. A progressive reduction in active bed width in reach 3 since 1932, and in reach 5 since 1957 is apparent. In 1932, the river had 2 or 3 dominant channels through reaches 2–4, but in 1957–82 only 1 dominant channel. This change seems to be associated with the relatively stable active bed widths in these reaches since 1957.

The number of low flow channels provides an index of braiding intensity (Figure 29). At present, the mean number increases from 6.5 in reach 7 to 10.4 in reach 4, then declines rapidly to 1.4 in reach 1. In 1932 and 1957, the number of low flow channels was greatest in reach 3, and declined rapidly downstream. Because active bed width decreases downstream at the same time as the number of channels increases, there is a more marked change in braiding intensity from reach 7 to reach 3 than Figure 29 suggests. In 1982, there were 6.0 channels per km width in reach 7 and 7.9 in reach 3. In reach 2 the river increasingly follows one main channel with 1 to 2 smaller side channels until its single thread tidal reach below the Old Highway Bridge.

Sedimentation In reaches 2 and 3, there has been aggradation of approximately 0.5 m since 1932 (Figure 30), which is equivalent to an annual rate of deposition of 84,000 m^3/year. During the same period, an average 125,000 m^3/year of gravel was extracted in reaches 2 and 3 with 85,000 m^3/year extracted from reach 4 during 1955–68 (R H Poynter, pers. comm.). The trend in these reaches was for aggradation of 152,000 m^3/year during 1930–55, scour of 25,000 m^3/year during 1955–68, and renewed aggradation of 62,000 m^3/year since 1968 (Table 7). Overall, gravel extraction has limited a potential mean rate of rise in bed level of 19.1 mm/year to only 7.7 mm/year over the period 1930–81.

The riverbed in reaches 4 and 5 has, on average, degraded at a mean rate of 3.4 mm/year, which is equivalent to removal of 61,000 m^3/year of gravel since 1930 (Figure 30). Changes in mean bed level in these reaches are less than downstream because any change in sediment storage is spread over a wider active bed (Figure 28). In reach 6 there was net mean

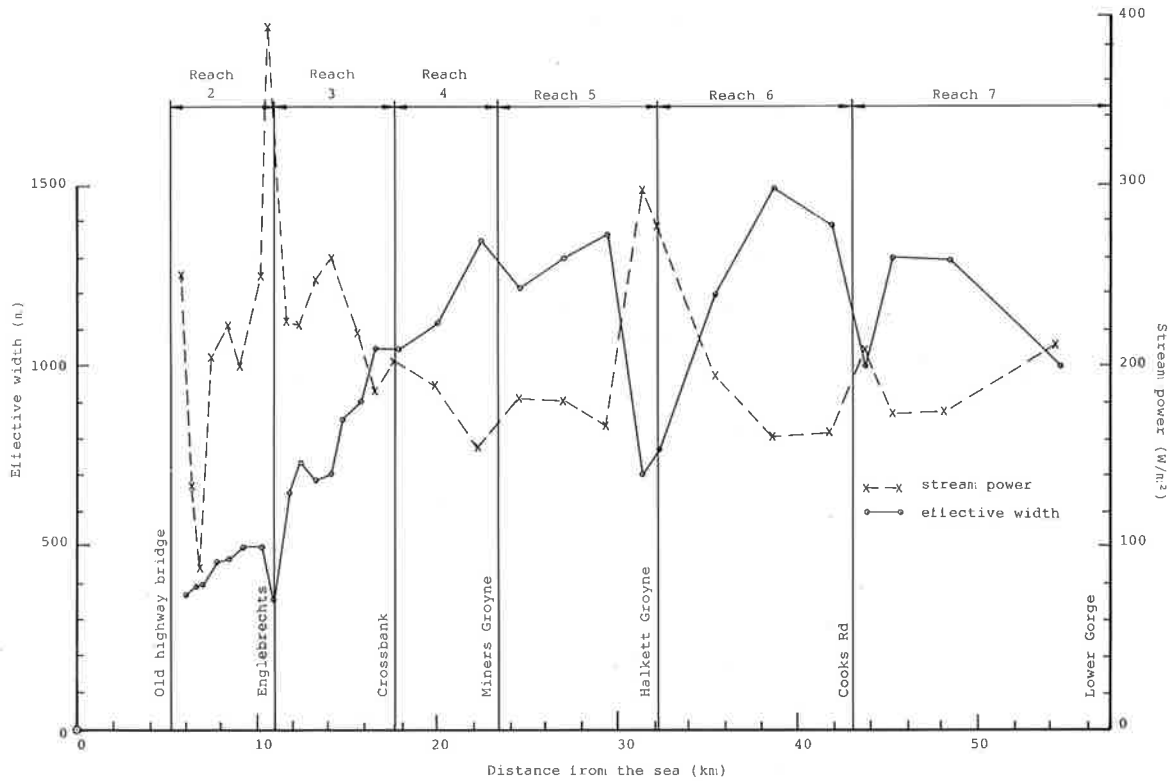


Figure 26: Effective width and stream power at design flood: 1976–82.

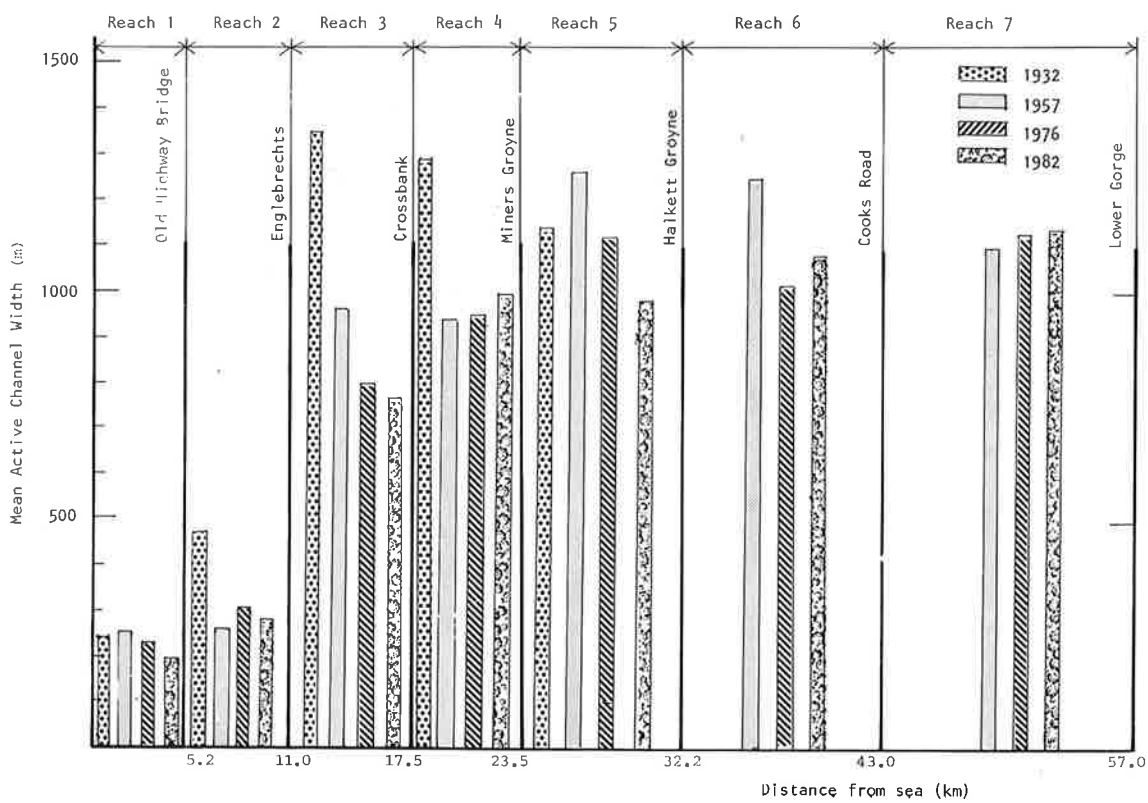


Figure 28: Mean active bed widths, Waimakariri River: 1932–1982.

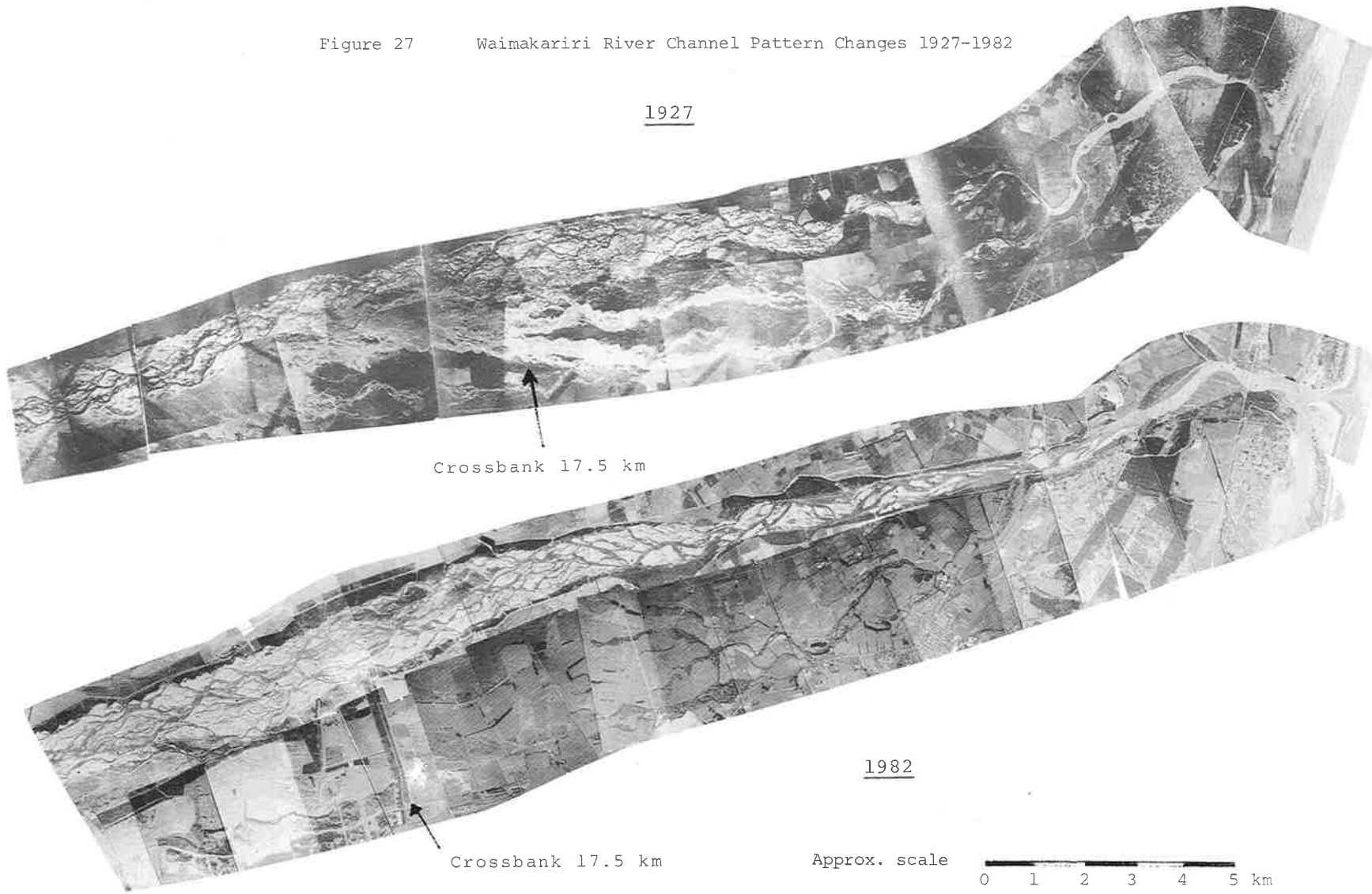


Figure 27: Waimakariri River channel pattern changes: 1927–1982.

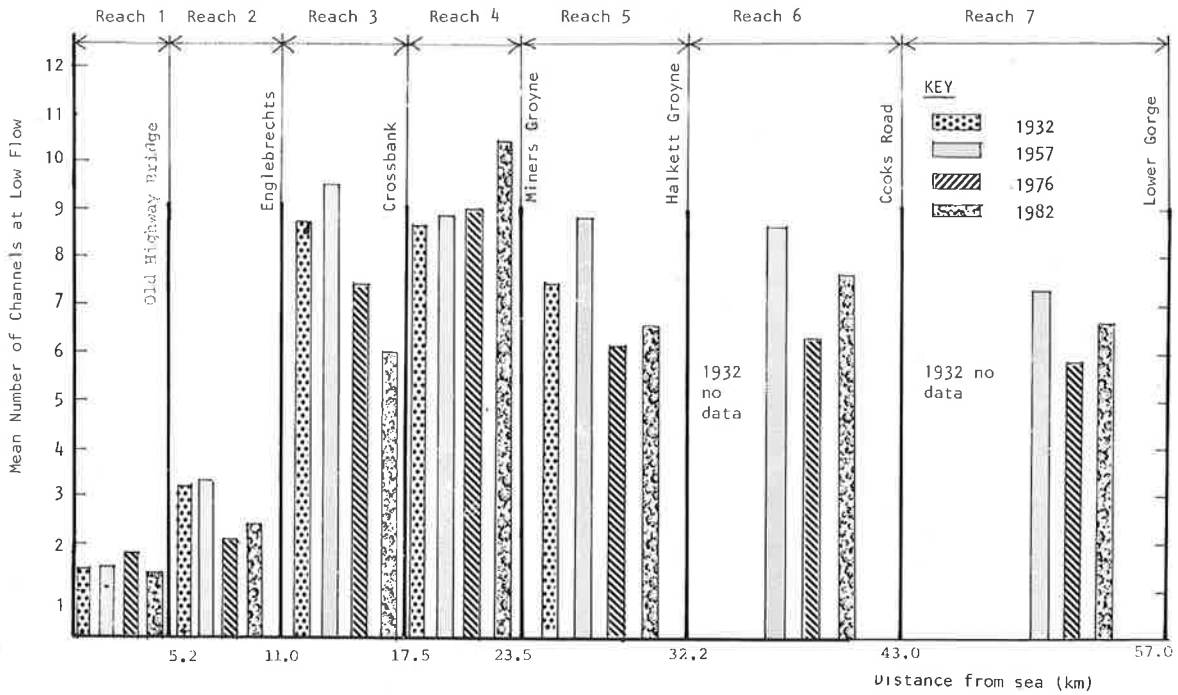


Figure 29: Mean number of low flow channels, Waimakariri River: 1932–1982.

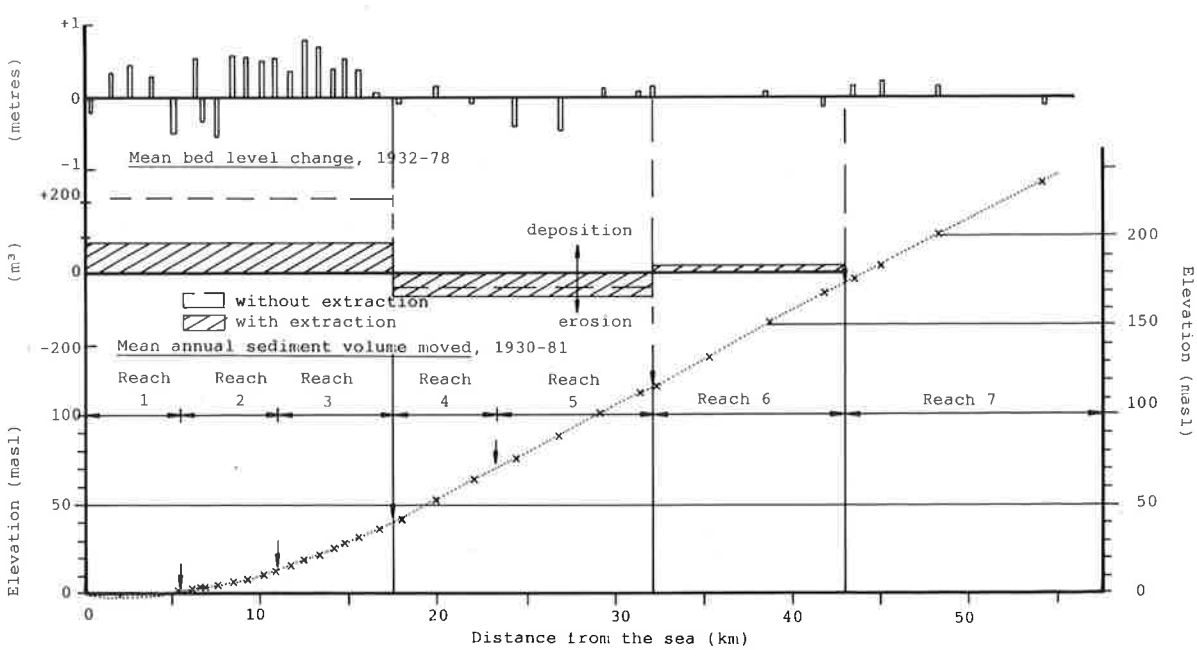


Figure 30: Waimakariri River: longitudinal profile and sedimentation patterns.

aggradation of 1.4 mm/year during 1930–81, but with a period of aggradation (7.0 mm/year during 1930–55) followed by degradation (4.4 mm/year during 1955–81).

Fluctuations in mean bed level are caused not only by long-term aggradation, but also by short-term changes, such as those caused by the passage of a bar past a cross-section. Since 1929, mean bed levels have fluctuated over a range of up to 0.4 m in reaches 6 and 7, up to 0.6 m in reaches 4 and 5, and up to 1 m in reaches 1 to 3. This downstream increase in bed

level fluctuations is associated with the downstream decrease in active bed width, which requires that changes in gravel storage be accommodated by more extreme changes in bed level.

To summarise the sedimentation trends for the period 1930–81 the upper reach has changed from aggradation to degradation since 1955, the middle reach has shown consistent degradation, while the lower reach has shown continuing aggradation, the bulk of which is supplied from channel reworking and bank erosion upstream.

Table 7: Waimakariri River sedimentation and erosion 1930–1981

	Year to period	Sea to Crossbank 0 to 17.5 km Lower reaches 1,2,3	Crossbank to Halkett Groyne 17.5 km-32.2 km Middle reaches 4 and 5	Halkett Groyne to Cooks Rd 32.2 km-43.0 km Upper reach 6	Sea to Cooks Rd Total reaches 1-6
Mean Active Channel Width (m)	1880	1190	2090	-	-
	1932	680	1350	1290	1060
	1957	590	1070	1310	930
	1982	560	1060	1120	870
Area of Active River Bed[1] (ha)	1880	2083	3078	-	-
	1932	1192	1991	1395[6]	4578
	1957	1027	1576	1415	4018
	1982	986	1557	1209	3752
Area of river conservation[1] planting (ha) (willows & poplars)	1932	66	0	No data	66
	1957	460	220	36	716
	1982	490	360	55	905
Net mean *annual* volume of sediment deposited/eroded[2] (m^3/yr) after gravel extraction	1930–1955	+152,000	−92,000	+98,000[7]	+158,000
	1955–1968	−25,000	−7,800	−63,000[7]	−95,800
	1968–1981	+62,000	−62,000	−53,000[7]	−53,000
	1930–1981	+84,000	−61,000	+19,000[7]	+42,000
Mean *annual* volume of gravel commercially extracted[2] (m^3/yr)	1930–1955	16,000	Negligible	Assumed	16,000
	1955–1968	254,000[5]	+85,000[5]	neglibible	339,000
	1968–1981	207,000	Negligible	amount	207,000
	1930–1981	125,000	+26,000		151,000
Gross *annual* sediment volume moved[3] (m^3/yr)	1930–1955	+168,000	−92,000	+98,000	+174,000
	1955–1968	+229,000	+78,000	−63,000	+244,000
	1968–1981	+268,000	−54,000	−53,000	+161,000
	1930–1981	+209,000	−39,000	+19,000	+189,000
Equivalent *annual* change in mean bed level[4] (mm/yr)	1930–1955	+13.7(+15.1)	−5.2(−5.2)	+7.0(+7.0)	+3.7(+4.0)
	1955–1981	+3.6(+24.6)	−2.0(−0.7)	−4.4(−4.4)	−1.8(+5.2)
	1930–1981	+7.7(+19.1)	−3.4(−2.2)	+1.4(+1.4)	+1.0(+4.5)

Notes: [1]Based on aerial photographs and maps.

[2]Based on Table 11 of Waimakariri 1982 report (Reid and Poynter, 1982) '+' indicates aggradation '−' indicates scour.

[3]Volume of sediment transported, plus volume of gravel extracted.

[4]Net annual volume of sediment transported divided by average area of active riverbed between survey dates. Figures in brackets are for gross annual sediment moved, i.e., including commercial gravel extraction.

[5]Assume 75% extraction, etc., below Crossbank and 25% immediately upstream.

[6]Calculated from cross-section active widths, Table 1, Appendix 1.

[7]Reach 6 is extended from Cooks Rd (43 km) to Jenkins Groyne (45 km) for sediment transportation data.

5 Impact of the Control Scheme on the River and its Environment

5.1 Effect on the River Channel

Comparison of Figures 9, 10, 11 and 27 shows that river control works carried out along the Waimakiriri River have had a marked effect on river morphology, which to some extent can be quantified by reference to the factors considered in Section 4. Under natural conditions, flows progressively diverged from the apex of the fan at Halkett, and there was no single channel capable of carrying all the discharge leaving the Lower Gorge to the sea. To prevent flooding of the developed fan surface, the control scheme has provided a single floodway along the line of the dominant channel at the time of European settlement, which is designed to carry floods of up to 4300 m^3/s.

The mean bankfull channel capacity (MBC) of the lower reaches has changed significantly in the 1929–1978 period. The RI for MBC in reach 2 has increased from 1 year to 2.3 years, while in reach 3 it has decreased from 3–7 years to 1 year (Figure 23). These changes are attributed in reach 2 to the opening up of Wrights Cut in the 1930's and the excavation of large volumes of gravel, mainly in the 1960's, and in reach 3 to the continuing deposition of gravel where the braided channel on the steep alluvial fan changed to a diverging, anastomosing channel network (Figure 2).

There is still a distinct transition from the mobile, unstable, braided channel pattern in the upper and middle reaches to a more confined, semi-braided pattern downstream from Engelbrechts (11 km) (Figures 27, 28 and 29). This coincides approximately with the toe of the fan and a marked decrease in slope (Figure 30), and also with the marked change in character of the river apparent in 1865 at this point (Figure 2).

Downstream, there is a distinct meander pattern with a wavelength of about 2 km and an amplitude decreasing from about 0.5 km at 11 km to 0.3 km at 6 km. The channel is guided by rock work, and appears to be stable. Upstream, the dominant channel of the braided reach commonly has a "pseudo-meandering" appearance, but it is free to migrate, and at Engelbrechts (11 km) it is out of phase with the pseudo-meandering dominant channel upstream. This lack of continuity in channel pattern was a contributing factor to the break-out at Engelbrechts during the 1957 flood (Henderson, 1960). Removal of islands and other obstructions to the flow has since reduced this problem, but a section just upstream, at 12.47 km, has the lowest flood capacity of the river. There is only about 20 m of willow protection between the active channel and the stopbank on the south bank, and this discontinuity of flow pattern could result in the stopbanks being attacked during a major flood by strong cross-currents, resulting in a breach. This reach of river appears to be the location at which the floodway has the highest risk of failure.

Two cross-sections, at 12.47 km and 19.93 km, are at present unable to carry the 100 year design flood, and a lowering of mean bed level by 0.16 and 0.06 m, respectively, would be necessary to provide a sufficiently large cross-section to pass 4300 m^3/s. At other cross-sections, aggradation of up to 1.43 m could be tolerated before the capacity of the floodway became too small to convey the design flood (Figure 31). However, the cross-section surveys indicate that there is a fluctuation in mean bed level at any one cross-section of between 0.1 and 0.2 m in the upper reaches to up to 1.0 m in the lower reaches, in response to the passage of gravel bars. Consequently, the "required" or "tolerable" bed level changes to provide capacity to convey exactly the 100 year flood must be seen in this context. Nevertheless, recent aggradation rates are such that, if continued, the capacity of the flood channel at cross-sections 13.27 and 22.27 km would also fall below the 100 year flood discharge in 5 and 27 years, respectively, and the capacity at 12.47 km will be reduced to that of the 10 year flood in 21 years.

The control scheme has provided a single channel which, at the design flood, has a roughly constant rate of energy expenditure of 210 W/m^2 in the effective floodway from

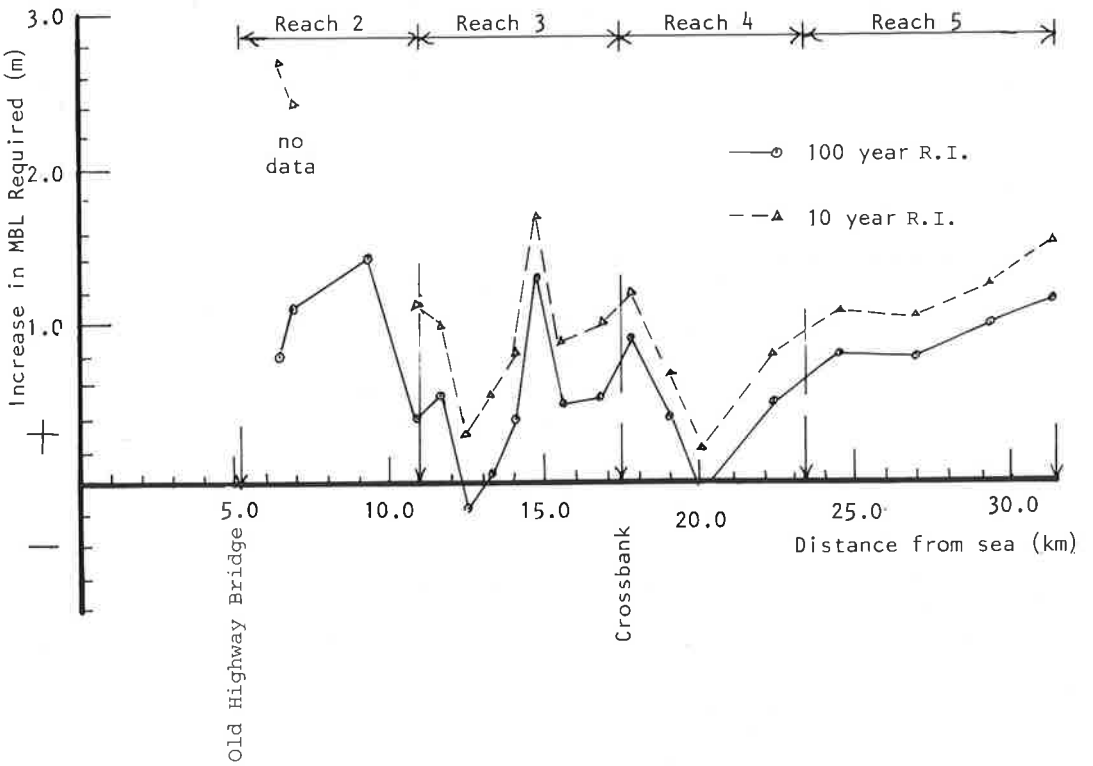


Figure 31: Required increase in Mean Bed Level for selected flood recurrence intervals.

Halkett Groyne to the Old Highway Bridge. This is in marked contrast to the natural situation, where flood flow and channel slope declined down-fan, and total floodway width increased, giving a marked down-fan decrease in stream power. At Engelbrechts (11 km), however, stream power at the design flood is nearly double the average, 400 W/m^2, this being related to the sudden decrease in effective floodway width coinciding with the discontinuity in channel patterns in this reach. It confirms the vulnerability of the control scheme of this reach of river.

The minimum rate of energy expenditure at the design flood is 86 W/m^2, at the head of Wrights Cut (6.86 km), where the local slope is only half the slope through the Cut. This suggests that this zone is one of potential aggradation. Indeed, a consequence of the control scheme appears to have been that there has been a large increase in stream power along the river, which has increased its ability to carry coarse sediment farther down-fan. Thus, the locus of coarse sediment deposition has been shifted from the middle and lower fan, where channels formerly diverged radially, to the toe of the fan and beyond, as far as the Old Highway Bridge. Since 1927, a tongue of gravel, which indicates the most downstream point to which gravel is transported, has advanced about 2.5 km down the river to a point about 2.5 km from the sea, but has now become stationary (Section 3.4). It is assumed that only in exceptional floods does gravel reach the river mouth.

In reach 6, there has been erosion of an average 58,000 m^3/year since 1955, and in reaches 4 and 5 there has been erosion of an average 39,000 m^3/year (Table 7). However, local source areas for riverbed gravel have decreased (Table 7), with a halving in the area of active riverbed from 1880 to 1957 in reaches 4 and 5 (see also Figures 2 and 11), and a decrease of 18% since 1932 in reaches 1 to 6. The availability of erodible banks and floodplain has also declined, as the area planted in poplars and willows has increased from 66 to 905 ha since 1930. However, the volume of gravel transported into the lower reaches appears to have increased by about 60% since extensive river control work began in the 1930's (Table 7). With the present size distribution of riverbed gravels, armouring is unlikely, so that elimination of bank erosion in the upper and middle reaches will simply induce erosion of the active

bed. The decrease in aggradation rates in reaches 1–3 is thus dependent more upon the current extraction rate of over 200,000 m³/year than upon upstream controls, and gross sedimentation rates (before gravel extraction) in the lower reaches have increased from 168,000 m³/year in 1930–55 to 268,000 m³/year in 1968–81. If commercial gravel extraction fell below about 150,000 m³/year aggradation in the lower reaches and a seaward advance of the gravel "tongue" would probably result.

5.2 Changes on the Floodplain

The Waimakariri River floodplain and fan area have changed markedly since man came to New Zealand, particularly since European settlement. The post-1940 changes in floodplain vegetation and land use have been a cause rather than an effect of the river control scheme, although the control scheme has permitted the changes to be maintained without excessive damage and may have encouraged developments that would not otherwise have occurred.

Land use, vegetation cover and population The river in the mid-nineteenth century had a wide, unstable, braided channel with bare, erodible banks, and the floodplain-fan surface was sparsely vegetated, with a native grassland-scrub community predominating. This depleted vegetation cover, relative to the pre-human occupation conditions (Figure 4), was at least in part the result of Polynesian hunting and settlement activities. The lowland-swamp area, on which Christchurch now stands, featured flax swamps, remnant pockets of podocarp forest and grasslands.

After European settlement, grazing became the dominant land use on areas where natural drainage and suitable soils existed, small market gardens were established in the Marshlands and Papanui areas, and the town of Christchurch began to develop. By 1982, land use had completely changed (Figure 32); urban Christchurch occupied one-fifth of the floodplain/fan area; communications, intensive agriculture, river control works and associated forest development occupied much of the remainder (Table 8).

Land use changes in the riparian zone since 1880 have been examined in more detail. The riparian zone is here defined as the active and recently active river channel as it existed in the year surveyed (Figure 9), and has been located with reference to roads and the early stopbank system, these features being common to all reference maps and aerial photographs. The areas of different vegetation classes could then be measured in the defined area for 1880, 1932, 1957 and 1982 (Figure 33). Because of the poor quality of the 1932 aerial photography, the areas of some vegetation classes, particularly scrub and rough pasture, were difficult to define, but the real changes in area of vegetation classes are large in comparison with possible errors, which are of the order of 5–10% of the respective vegetation areas.

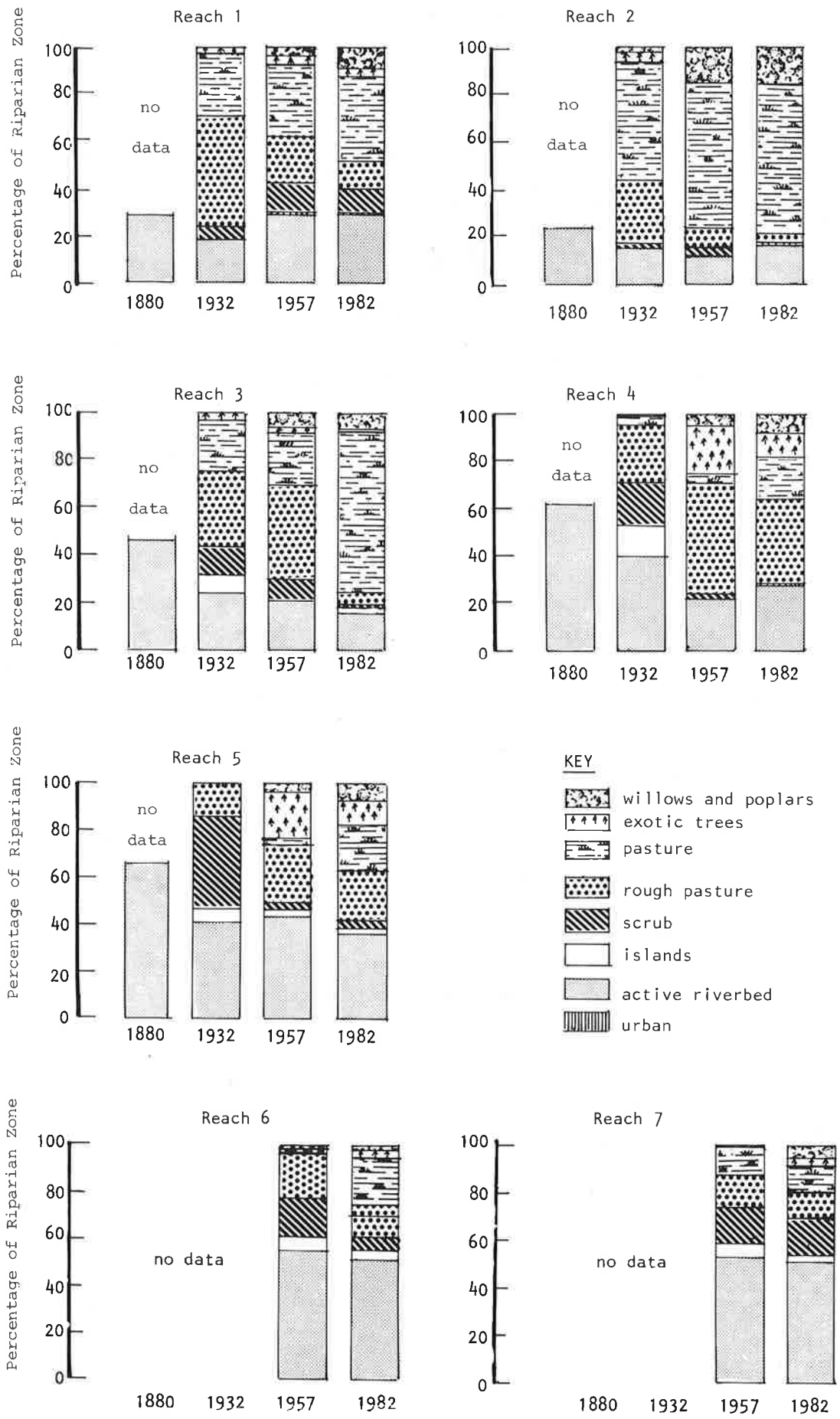
The proportion of the riparian zone in active riverbed has shown little change in reaches 1 and 2, but in reaches 3 and 4 it had decreased from between 50 and 60% in 1880 to close to 20% by 1957, with no significant change since. In reach 5, there has been a decrease from about 65% in 1880 to 40% in 1932, with changes since then being close to the level of

Table 8: Land use, Waimakariri floodplain/fan 1976–77

Land use	Area (ha)	Percentage
Sand dunes	1190	2.1
Scrubland	760	1.4
Exotic forest plantations	2830	5.1
Grassland—extensive	6170	11.0
intensive	13 300	23.7
Grassland/horticulture	11 870	21.2
Lagoons	1130	2.0
Riverbed	7120	12.7
Urban/industrial	11 630	20.8

Source: LRIS sheets

Figure 32: Waimakariri River floodplain land use and vegetation (1975–79).


Reach 1
Reach 2
Reach 3
Reach 4
Reach 5
Reach 6
Reach 7
Percentage of Riparian Zone
100
80
60
40
20
0
no data
1880
1932
1957
1982
KEY
willows and poplars
exotic trees
pasture
rough pasture
scrub
islands
active riverbed
urban

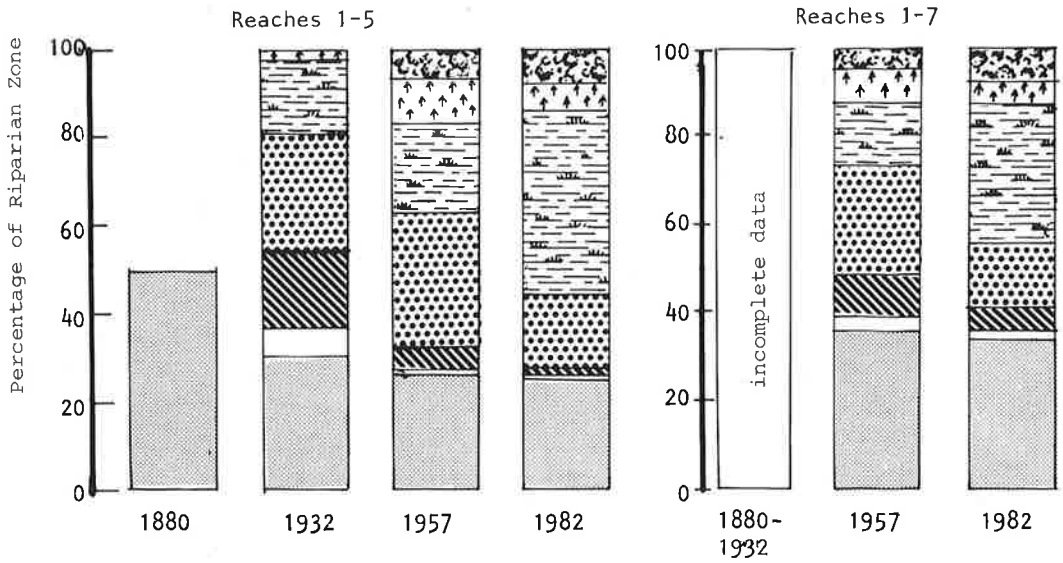


Figure 33: Vegetation and land use changes in the riparian zone: 1880–1982.

accuracy of the measurements (5–10%). In reaches 6 and 7, the proportion of active riverbed has remained close to 50% since the first photographs were available in 1957. Most of the decreases in active riverbed area have thus occurred in the middle of the fan zone of the river system (reaches 3, 4 and 5).

The area of scrub-covered islands (those areas surrounded by active riverbed) decreased from about 8% in 1880 to about 1% by 1957, with no subsequent measurable change. Most of this decrease has occurred in reaches 3 and 4 because the anastomosing channel system has been trained into a single confined braided channel system by river control works. The area of scrub-covered bermland in reaches 1–5 has decreased from 18% of the riparian zone in 1932 to about 2% in 1982, with most of this change occurring in reach 5.

The proportion of the riparian zone in rough pasture in reaches 1–5 has decreased from 27% in 1932 to 16% in 1982, with the proportion in reaches 1, 2 and 3 decreasing and in reaches 4 and 5 increasing. No significant changes in the area of rough pasture have occurred in reaches 6 and 7 since 1957.

The proportion of developed pasture (or grasslands) in reaches 1 to 5 increased from about 16% in 1932 to 42% in 1982, mostly since 1957. All reaches showed increases, particularly reach 3, where the proportion has increased from 21 to 67% (1800 ha), mainly since 1957. Reach 6 showed an increase from 3 to 20% from 1957 to 1982 with no change in reach 7 for this period.

The area in exotic forests (primarily *Pinus radiata*) in reaches 1–5 increased from 2 to 10% of the riparian zone from 1932 to 1957 and then decreased to 6% in 1982. Reaches 1–3 and 6–7 have no significant areas in exotic forest, while reaches 4 and 5 showed major increases from negligible areas in 1932 to a peak of 20% of the riparian zone in forests in reach 5 in 1957. The decrease to 11% by 1982 is mainly attributable to the logging of the 1930's plantings and wind-throw destruction in the August 1975 storm. Plantings in reaches 6 and 7 have recently increased.

Conservation plantings (willows and poplars) have increased steadily in reaches 1–5 from a negligible area in 1932 to 8% of the riparian zone in 1982, with all reaches contributing to this increase.

The land use changes in the riparian zone are either a direct consequence of the river control works, or would not have been possible without them.

Further away from the river, market and social forces dominate, but the scheme has nevertheless facilitated land use changes, by reducing the risk of flood damage and thus

encouraging development. In the first 50 years of settlement, land development was a primary cause of the river control scheme, but as the risk from flood damage decreased, further development can be attributed in part to the scheme works themselves.

Population over the whole floodplain/fan area has increased by 138% since 1936, from about 100,000 to 250,000 today (Table 9). There has been slow growth in the inner city, but rapid growth in the outer suburbs. The populations of Waimairi District and Paparua County grew by 396 and 435%, respectively, during 1936-82, with a tendency for growth to predominate on areas towards the river.

Land values and potential costs of flood damage Current land and capital values in each county or borough with part or all of its area within the floodplain/fan have been adjusted by the proportion of their area within the floodplain area. This gives total values for the whole area of $1375 million for land values and $3566 million, for capital values (Table 10). These values have in turn been weighted using NCCB flood risk classification weightings (Brown and Copeland, 1982, p. 25). This procedure assumes that capital and land values are distributed uniformly over each county or borough and that the weightings are a true reflection of flood risk. However, these assumptions are not entirely true, because there are other uncertainties, such as the location of a break-out from the floodway, which are probably of greater significance. It is still considered reasonable to allocate a higher value to assets at risk near the river, than those further away from known flood paths. This is the basis of the flood risk "weightings". The weighted capital value averages $17,300/ha over the whole floodplain/fan (Table 10). Values range from $82,000/ha for Riccarton Borough to $2200/ha for the rural Eyre County, although the relative flood risk factors are 0.20 and 0.61, respectively. Kaiapoi Borough has a weighted capital value of $127,000/ha because of its high flood risk classification.

Table 9: Waimakariri River floodplain/fan population

County or Borough[4]		Floodplain area (km^2)	Number of people per km^2			
			1936	1961	1981	Population growth rate[2]
Christchurch City	urban	94.6	1,975	1,430	1,550	79
Riccarton Borough	urban	3.3	1,623	2,220	2,020	24
Kaiapoi Borough	urban	3.2	499	1,100	1,520	206
Waimairi District	urban rural total	31.0 80.9 111.9	129	350	1,805 179 628	386
Eyre County	rural	93.2	4	4	7	74
Paparua County	rural	208.3	13	35	71	453
Urban Area[3] Rural Area[3]		132.3[1] 382.3[4]			1,622 78	no data no data
Total Floodplain	: Area : Densities[1] : Population[2]	514.5	 239 102,407	 427 192,997	 548 244,105	 138

Notes: [1]Data from Statistics Department, Christchurch: assumes population evenly spread over the whole county.

[2]Increase since 1936 expressed as a percentage of the 1936 population.

[3]The urban area is a combination of Christchurch City, Riccarton and Kaiapoi Boroughs and urban areas of the Waimairi District; the rural area is a combination of Eyre and Paparua Counties and includes rural areas of the Waimairi District.

[4]The population in the Maivern and Oxford Counties living in the floodplain is negligible.

Table 10: Waimakariri River floodplain: weighted capital and land values[1] at risk from floods (×$1000, 1982 values)

County or Borough[2]	Floodplain C.V.[3]	Floodplain L.V.[3]	Weighting Factor[4]	Weighted C.V.[4]	Weighted L.V.[4]	Area within floodplain (ha)	Area of Class I & II land (ha)	Weighted C.V per hectare of floodplain	Weighted L.V. per hectare of Class I & II land[5]
Christchurch City (urban)	2,028,476	807,157	0.180	365,126	145,288	9,456	382 mainly urban	38.6	urban therefore not applicable
Riccarton Borough (urban)	136,136	56,474	0.200	27,227	11.295	332	urban	82.0	
Kaiapoi Borough (urban)	60,779	16,696	0.670	40,722	11,186	320	urban	127.3	
Waimairi District (peri urban)	1,058,155	370,102	0.331	350,249	122,503	11,200	3,094	31.3	39.6
Eyre County (rural)	33,115	18,743	0.607	20,100	11,377	9,321	2,539	2.2	4.5
Paparua County (rural)	249,315	106,302	0.327	84,796	34,761	20,830	7,411	4.1	4.7
Totals	3,565,976	1,375,474		888,220	336,410	51,459	13,426	17.3	12.6

Notes: [1]Data source: Valuation Department, Christchurch.

[2]Floodplain in the Oxford and Malvern Counties is excluded because of its small area (4972 ha), over half of which is riverbed, the balance being mainly in farm forestry or scrub, and having no permanent dwellings.

[3]C.V. and L.V. are adjusted in proportion to the area of the County or Borough lying within the defined floodplain.

[4]Weighted C.V. or L.V. = floodplain C.V. or L.V. multiplied by the sum of the proportion of the area of County or Borough in each classification zone times its relative classification zone weighting.

[5]Rural Counties only: excludes Christchurch, Riccarton, Kaiapoi urban areas.

Property values have risen by an average 4.5% per annum since 1966 (Brown and Copeland, 1982) and this, combined with the increasing population on the floodplain/fan, highlights the significance of the Waimakariri River control scheme.

It is very difficult to give a reliable figure for the cost of flood damage of a break-out from the present floodway (Brown and Copeland, 1982). The value of "saved flood damages" (those costs which would have occurred had there been no control works carried out) increased in response to the increase in value of floodplain assets, and the increasing level of protection afforded by river control works, particularly since 1930. When flood control benefits are assessed, all of this capital value increase is included, although only part of this growth can be directly or indirectly attributed to increased protection from flooding resulting from improved river control works (Brown and Copeland, 1982, p. 33). Land enhancement, an increase in land or capital values in the Class A and B (high risk) floodplain areas, has occurred as a direct result of improved river control works. Such areas include McLeans Island, Coutts Island, riparian lands and urban and rural property close to the river. An important factor in the analysis of the costs and benefits of river control works is that, when the design capacity of the river control works is exceeded by a major flood, flood damage is usually much greater than if no river works had been carried out, because capital improvements in riparian and high risk areas of the floodplain have been made in response to a perceived decrease in the risk of flood damage. This extra flood damage decreases the value of the total annual saved flood damages, i.e., the net saved flood damage costs are less because of the increased capital developments near the river induced by the apparent protection afforded by the control works.

For the Waimakariri River, the present value of the floodplain assets (weighted for flood risk) is large with respect to the total river control costs (8.3:1) as a result of the high value of urban land which has 12 times the value per hectare and 20 times the population density of rural land. The ratio of floodplain assets at risk to river control expenditure will tend to increase because of:

(i) further intensive development of the 134 km^2 of Class I and II soils (mainly for horticulture and cash cropping);

(ii) further expansion of urban and industrial areas of Christchurch towards the river.

5.3 Groundwater

Flow Losses

Groundwater beneath the central Canterbury Plains, between the Waimakariri and Rakaia Rivers, is recharged by both rainfall and infiltration from rivers (Bowden, 1983, p 69). The Waimakariri River is the dominant source for recharge of the aquifers under the recent floodplain/fan, while the deeper aquifers beneath the older outwash gravels appear to be more influenced by long-term rainfall trends (Bowden, 1983; Cooper, 1980; Donaldson, 1977; Mandel, 1974). The main zone of infiltration losses from the Waimakariri River is in the middle fan between Crossbank and Halkett Groyne, and particularly over the 5 km stretch from Halkett to West Melton (Figure 34). Evidence from the flow loss gaugings (Figure 36) indicate losses in a reach from 10 km upstream to 5 km downstream from Halkett, and well data confirm that recharge occurs downstream from Halkett Groyne, where piezometric contours are convex (Figure 35) (Bowden, 1983, p. 57). Losses upstream from Halkett Groyne are probably to river underflow rather than groundwater, because the groundwater level is higher than river level from the Lower Gorge to Halkett Groyne (Figure 34).

The location of major flow losses coincides with that of the points of divergence of distributary channels southwards across the fan (Figure 9). These old channels are the primary sources of the spring-fed streams draining the lowland and former swamps in the Christchurch area. The discharges of the Styx, Avon, Halswell and Heathcote Rivers corre-

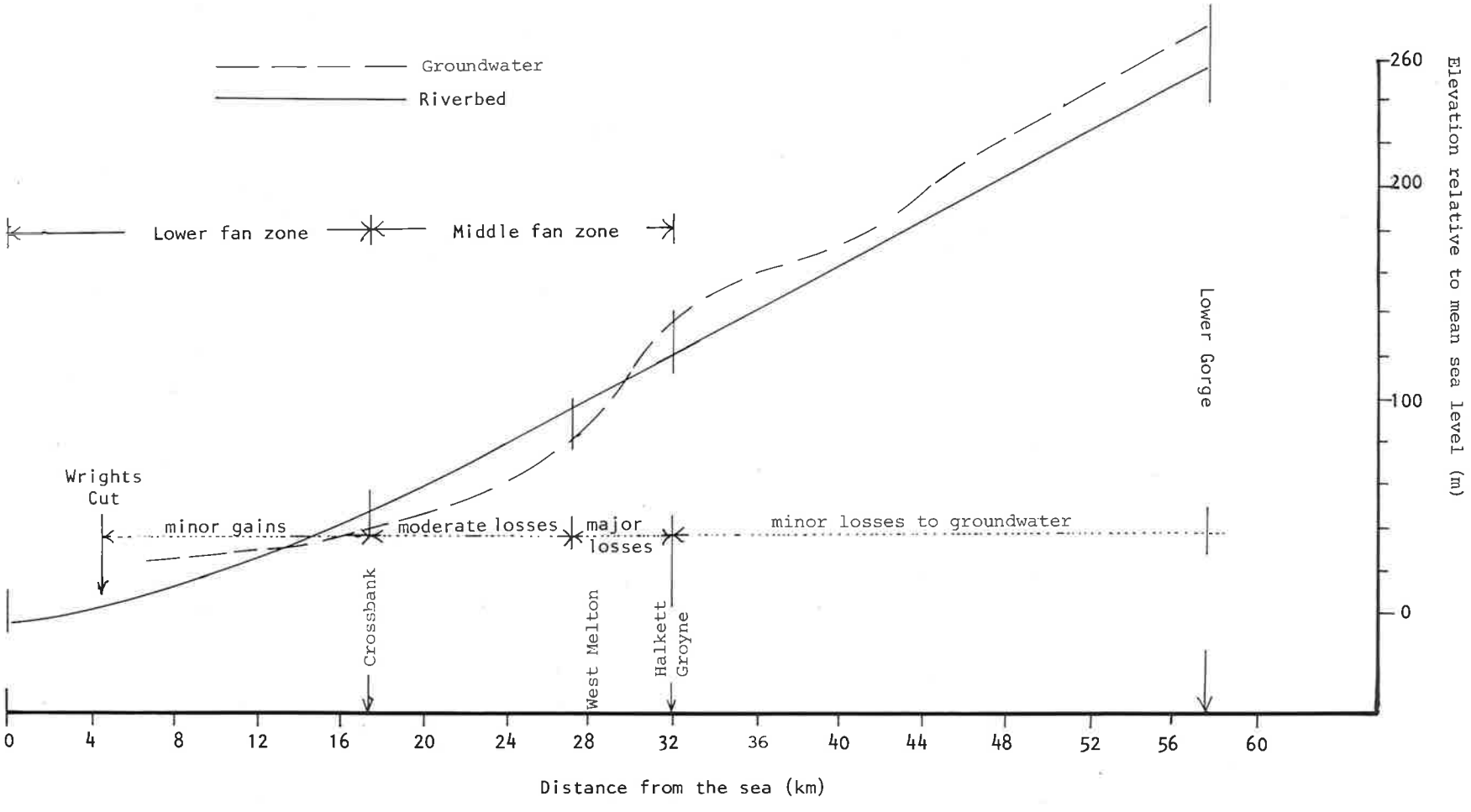


Figure 34: Groundwater levels in relation to riverbed levels for the Waimakariri River. (Sources: Mandel, 1974; Cooper, 1980)

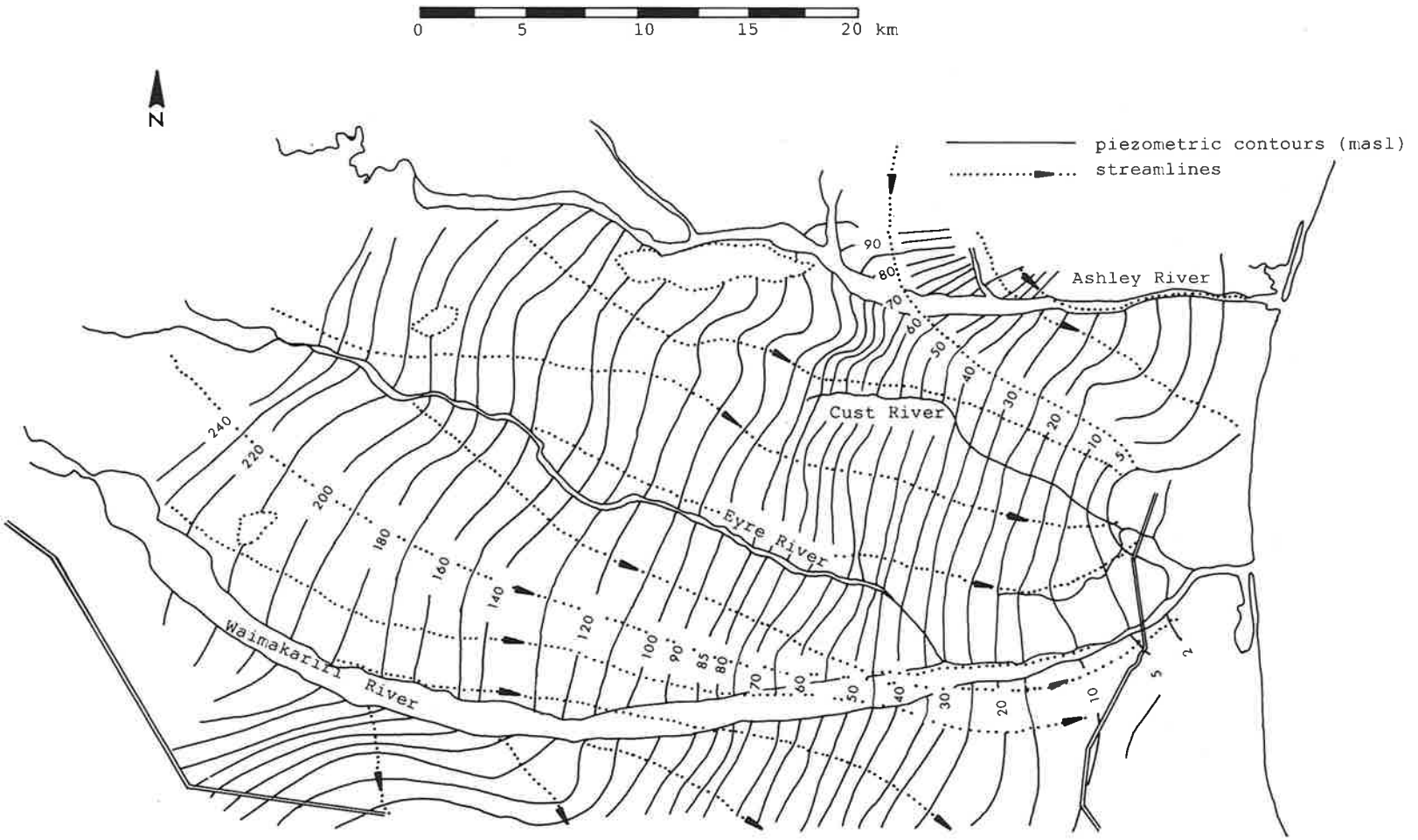


Figure 35: Piezometric contours and streamlines for northern Canterbury Plains.

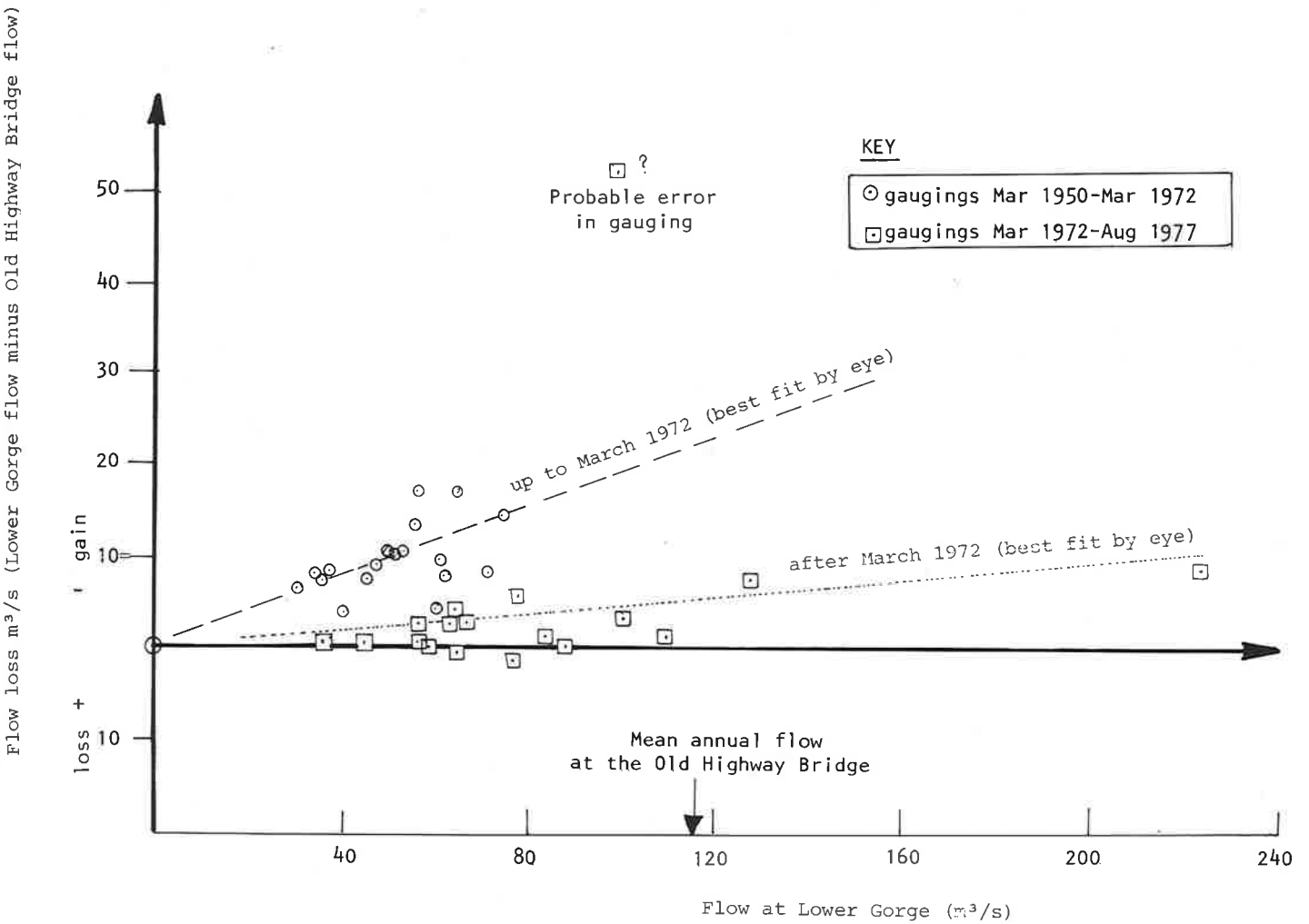


Figure 36: Flow losses on the Waimakariri River (Lower Gorge and Old Highway Bridge).

late with losses from the Waimakariri River (Mandel, 1974, p. 22), although their response to flow variation in the Waimakariri River is complex.

Flow losses have not been proven to the north of the river (Bowden, 1983, p. 57), although water probably flows from the present active riverbed to the Old North Branch in the vicinity of the 12–14 km reach, giving rise to the spring-fed southern tributaries of the Kaiapoi River.

Typical flow loss for low flow conditions up to March 1972 was 10 m^3/s (20% of the low flow) but since March 1972 it appears to have declined to about 2.5 m^3/s, or 5% of the low flow. Losses generally increase with increasing flow over the range of measured losses (Figure 36).

The Effects of River Control Works

The significant decline in flow losses (an unknown proportion of which provides groundwater recharge) since 1972 (Figure 36), is most likely attributable to the construction of two major groynes upstream of Halkett Groyne (1971–72) and six others in the West Melton reach downstream (1973–74) (Cooper, 1980). The main Waimakariri River channel system has subsequently flowed towards the north side of its active riverbed, away from the location of the divergence points of its former channel system (Figures 9 and 37).

Channel degradation upstream of Halkett Groyne, which averaged 0.074 m between 1929/32 and 1977/8 on five cross-sections in the reach between 32.19 and 41.84 km, may also be a contributing factor. Hydraulic gradient would only be reduced slightly in the aquifers, but a small incision of the active channel could isolate a significant fraction of the thin, gently dipping layers of gravel which make up the aquifers. Certainly, sedimentation has reduced the available area of aquifer recharge upstream and downstream of the Halkett Groyne. The construction of groynes and the subsequent planting of the bays created between them has induced deposition of silts and sands in these bays during floods, and the development of a new bank line approximately in line with the ends of the groynes. Former areas of active riverbed have thus become covered in a layer of silt, sand and willow tree roots, up to about a metre in depth. The active channel width at a section 500 m upstream from Halkett Groyne declined by 30% from 1147 m in 1932 to 800 m in 1982. Most of this reduction was on the south side of the river, with a 244 m reduction between 1957 and 1975 (Figure 38).

Prior to 1875, at least 6 major embankments were built and willows established upstream and downstream of what is now Halkett Groyne. Frequent overflows from this reach along flood channels leading to the lower floodplain would have previously recharged the shallow aquifers downstream. With these overflows now cut off by stopbanks and with recent siltation on formerly active riverbed, present infiltration rates in the Halkett/West Melton area are probably significantly less than before the construction of river control works. Because the groundwater under Christchurch, known to be exclusively derived from river seepage (Taylor and Stewart, 1978), is several decades old, it is possible that the effects of these changes will not be measurable for some time.

5.4 Wildlife

Birds

The indigenous New Zealand wildlife was almost entirely avian; the Europeans introduced many additional bird species, together with most of the terrestrial animals. There is little factual information on the species using the riverbed, floodplain and fan habitats before the Europeans arrived, and even less about wildlife populations before the Polynesians (Appendix 2). However, O'Donnell and Moore (1983) indicated that the Waimakariri River and similar rivers in Canterbury provide an internationally rare and vulnerable habitat for aquatic birds, notably the endemic wrybill plover (*Anarhynchus frontalis*), black-billed gull (*Larus bulleri*) and black-fronted tern (*Sterna alhostriata*).

Thirty-nine species of birds have been observed on the riverbed, 19 of which are wetland species. The dominant species is the black-backed gull (*Larus dominicanus*), large colonies of which are present below the Gorge. The riverbed habitat, which provides feeding areas along the shallow margins of channels and in the minor braids and backwaters, nesting areas on the gravel bars, and areas for "loafing", preening, etc, has been markedly modified by river control. A reduction in active bed area and width and the number of low flow channels (already discussed) implies a reduction in the availability of nesting and feeding habitat. In addition, although the present riverbed is probably more open and bare than in pre-Polynesian times, there has been vigorous encroachment of exotic vegetation types, particularly lupin, gorse, broom and willow, on to the riverbed and islands. Stopbanking below Halkett Groyne has markedly reduced wetland areas—swamps, flood channels, and backwaters—and has tended to increase flow depths in the constricted channels, particularly in reach 2. A major change associated with floodplain development and flood control has been the drainage and loss of the swamp-wetland around the margin of the fan.

Changes in vegetation and land use in the riparian zone as a result of river control (discussed in an earlier section) have also had a marked effect on the terrestrial habitat for birds. At least 20 species of bird, including 6 native species, frequent the riparian zone. Its area and diversity of vegetation have increased since 1850, providing additional nesting and breeding habitat, although unlike the riverbed habitat, it is not in short supply. On the other hand, the area of stable islands in the lower 30 km of river has decreased from 760 to 160 ha since 1880, which represents loss of an important habitat secure from predators and close to aquatic food sources.

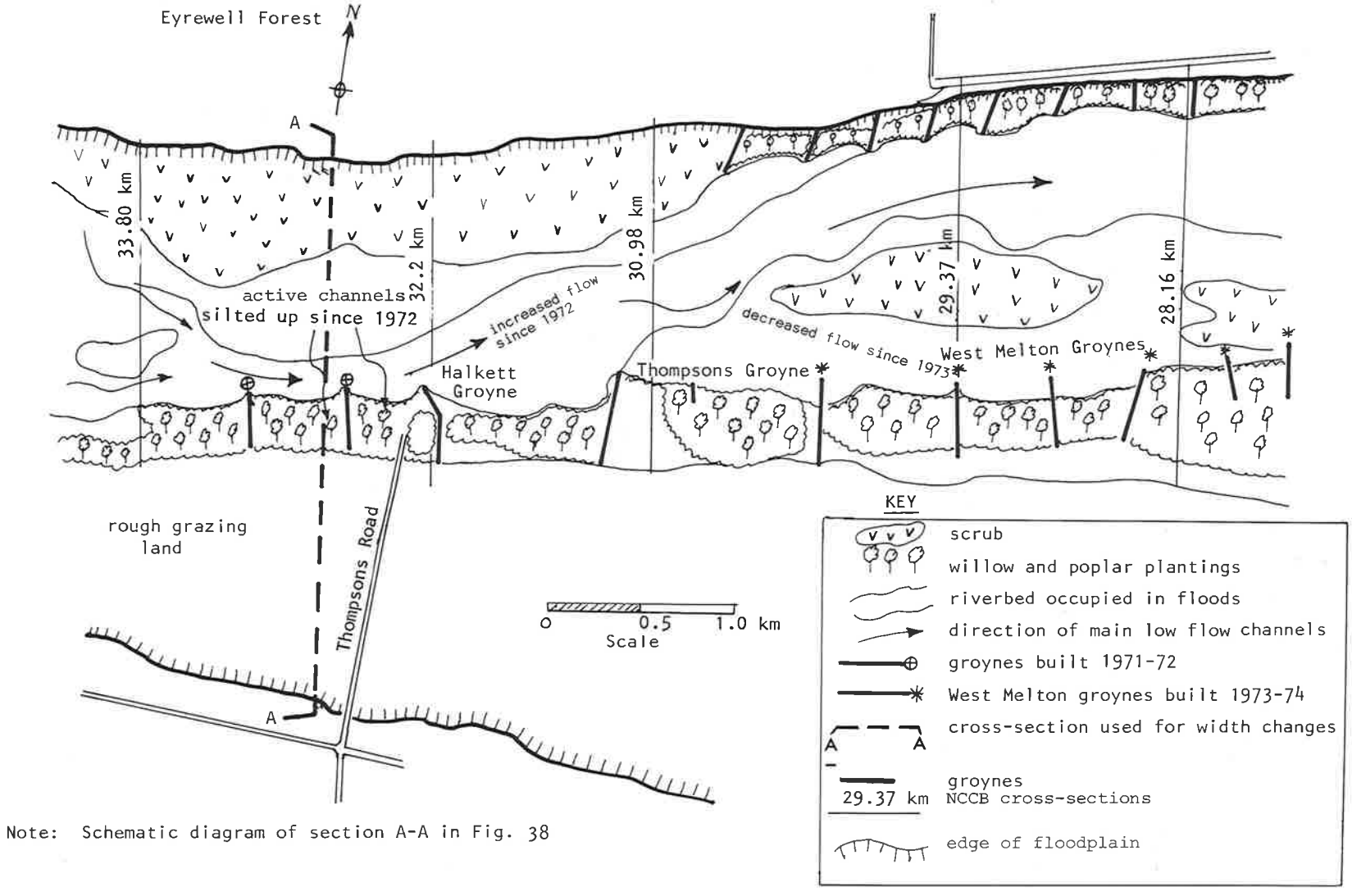
The value of the riparian zone for bird habitat is reduced by occasional disturbance from machinery associated with river control works, and also more frequently by recreational users, particularly trail-bike riders. Gravel extraction on the riverbed is an integral part of river control strategy and this too disturbs areas of potential habitat in the lower reaches, although such areas are less important than in the upper reaches.

The river mouth habitat is of major importance, with 48 bird species being recorded there and in Brooklands Lagoon. The character of this whole area is a result of river training and control, and is markedly different from the pre-European condition. Under natural conditions there were three mouths used by the river, depending upon the location of the channels on the fan area upstream. The location of the river mouths would have been less stable than the present fixed mouth, although there would probably have been smaller, less frequent floods reaching the mouths because of the very different channel pattern before man arrived. The present mouth has a sand-silt bed; the control scheme could result in passage of gravel to the mouth, lagoon and shore, the ecological consequences of which would require specialist study.

Overall, the rich, diverse natural environment provided by the Waimakariri River and floodplain/fan had become relatively bare and impoverished, but has been subsequently changed to give a more diverse range of habitats with more shelter. The value of the present river for wildlife is rated as outstanding by O'Donnell and Moore (1983), and the river mouth is rated as having a high value. The 50% reduction in area of the braided riverbed since 1850 has not had a serious effect on bird populations (Moore, 1983, pers. comm.), but development of the riparian zone as part of the control scheme and for pastoral production or forestry has substituted habitat types which are already common, and seem to be suited more to the introduced than the native bird species.

Fish

The river control scheme has had a major impact on the fish habitat of the Waimakariri River (Appendix 3).



Note: Schematic diagram of section A-A in Fig. 38

Figure 37: Channel pattern changes: Halkett-West Melton reach of the Waimakariri River. (From Cooper, 1980)

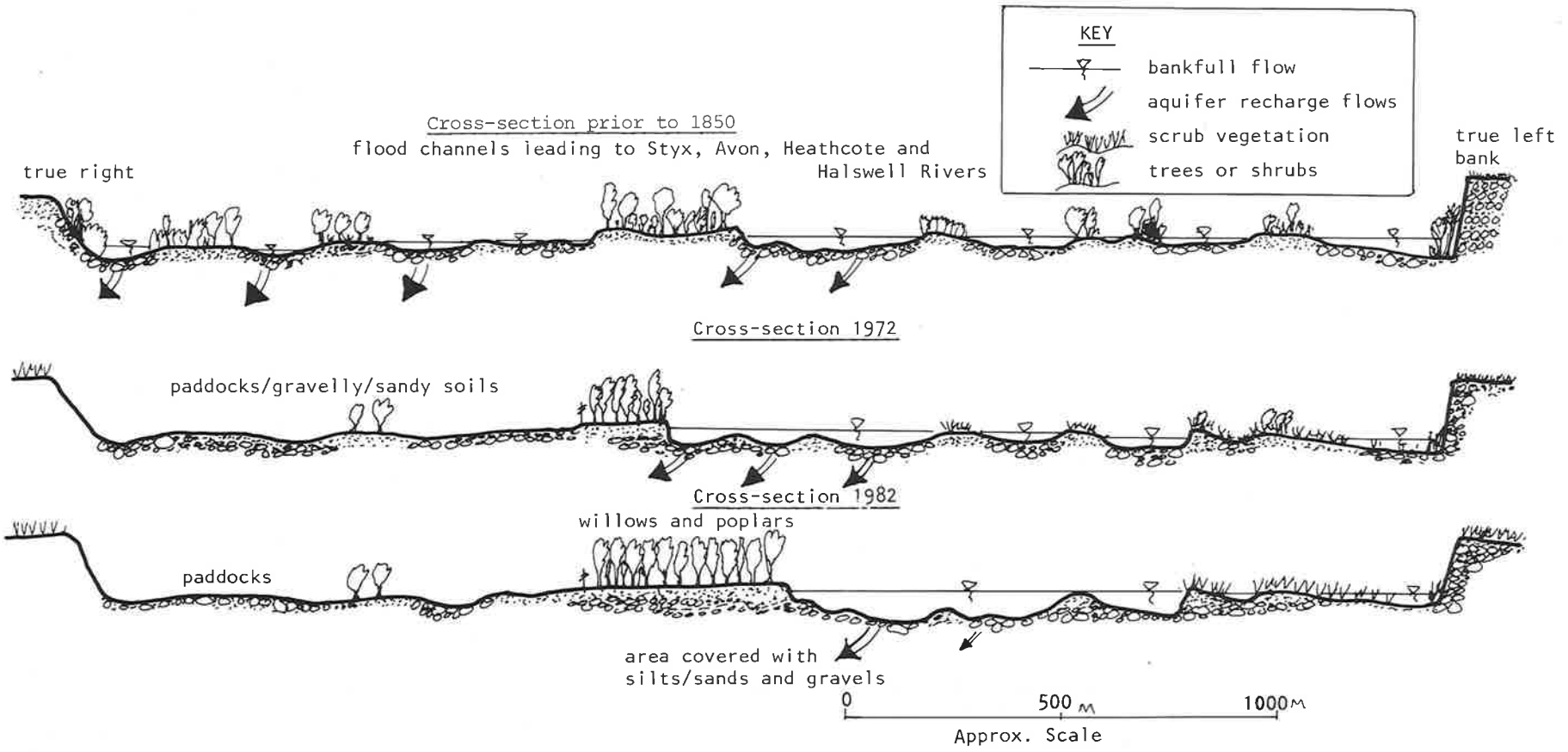


Figure 38: Schematic diagram of floodplain cross-section 500 m upstream of Halkett Groyne. (Section A–A on Figure 37)

Benefits to fish from control works

(1) There has been an increase in fish cover through the development of deep scour holes and quiet backwaters at groyne heads, and from streamside willows and other organic debris creating protected areas of deep water along the stabilised banks (Figure 17). Extensive rock rip-rap in the middle and lower reaches has created excellent cover in the form of cracks and holes for eels and other secretive fish.

(2) The planting of willows, poplars and more recently new tree and shrub species, has significantly increased the food supply for fish by improving insect habitat, leading to an increase in the river's invertebrate drift, an important food source for stream living fish.

(3) In the lower reach it is probable that the confinement of the river to a single floodway with one stabilised mouth has increased the low flow depths, improving fish cover and providing a secure access for migrating sea-run quinnat salmon in their passage upstream.

(4) The blocking of distributaries leading to the spring-fed old North and South Branches, and Styx, Avon, Halswell and Kaiapoi Rivers, has allowed these waterways to develop stable gravel and cobble bedded channels, protected from the effects of floods.

(5) The stabilised river mouth allows the estuary (Brooklands Lagoon) to function as a true tidal environment, reducing the frequency of damaging floods, and creating a more stable and secure habitat for fish.

Disadvantages

(1) The confinement of the main river channel to a single, broad floodway has encouraged the frequent movement of sediments, including gravels, downstream, into former relatively stable silt bed channels. This leads to the frequent destruction and reconstruction of riffles and pools used by many fish for spawning and cover during their life in the river (Appendix 3, Figure 1).

(2) The drainage of extensive riparian swamps and clearance and channelisation of former forested streams have caused a major reduction in wetlands for eels, inanga, kokopu and other fish species dependent on such environments.

(3) Major extraction of gravel in the lower reaches probably causes increased fine sediment loads and channel instability downstream during freshes and floods, generally reducing the quality of fish habitat.

Overall, the river control scheme has been beneficial for fish, providing more cover along the stabilised banks relative to the 1950's condition, protecting the lower spring-fed streams from flood damage and stabilising the Brooklands Lagoon. However, there could be a loss of certain types of habitat if the gravel load of the river reaches the river mouth, changing the lagoon's character from a silt and sand bed to a gravel system.

5.5 Water Quality

There are few data on the water quality of the Waimakariri River (Appendix 4). However, it is apparent from the studies to date that the quality of water in the main river upstream of the South Branch confluence (about 6 km from the sea) is high, except for periods of flow when the discharge is sufficient to mobilise fine sediments. As an approximate guide, the river is discoloured by suspended sediments when the flow exceeds 100 m^3/s, which is about 40% of the time (Figure 5). It is probable that river control works have increased the percentage of time the lower river (downstream from the Crossbank) is discoloured, by confining flood flows to a single floodway and maintaining a large vegetation-free active riverbed. Gravel extraction in the lower reach also contributes to water discolouration.

The blocking of channels leading to the spring-fed lowland streams has allowed them to build up and maintain a rich and diverse benthic flora and fauna. Stable bed sediments, free

from major flood flows, contribute directly to the high quality water and biological communities of these protected streams.

The development of an increasingly dense and diverse screen of vegetation along the stabilising riparian land of the main river has helped reduce pollution inputs in the form of eroded sediments, agricultural chemicals and animal wastes. With the present low level of agricultural and industrial development on the floodplain upstream from the Crossbank (17 to 57 km), the only source of "pollution" to the main river would appear to be the mobilisation of fine sediment from the active riverbed. Assuming the present land use trends continue on the middle and upper floodplain, this situation is likely to continue.

Overall, while the river control scheme appears to have had little effect on water quality in the main river, other than a probable increase in suspended sediment levels in the lower reaches, it has had a beneficial effect on the lowland spring-fed streams. Although not a consequence of the river control scheme, it is noted that effluent from a freezing works is a major source of pollutants to the lower reaches (downstream of State Highway 1).

5.6 Landscape

The appearance of the river and neighbouring areas (the riverscape) has undergone major alteration since Europeans arrived.

The riverscape in reaches 6 and 7 consists of an open, braided channel system with scattered scrub-covered islands. Bermlands covered in scrub, trees and rough pasture, and a sequence of stepped terraces which increase in height upstream, enclose the riverscape as seen from the floodplain or riverbed (Figure 39). The Torlesse Mountains, with peaks up to 2000 m and a winter snowline at about 1200 m, provide a background to the view upstream which contrasts sharply with the featureless horizon seen when looking downstream.

The upper zone has undergone only limited change as a result of river control works. The main visual effect is the change in bermland vegetation from scrublands to pasture and exotic tree plantations over the last 120 years. Willow plantings along Kimberley Cliffs have softened the impact of these previously eroding terraces (Figure 40).

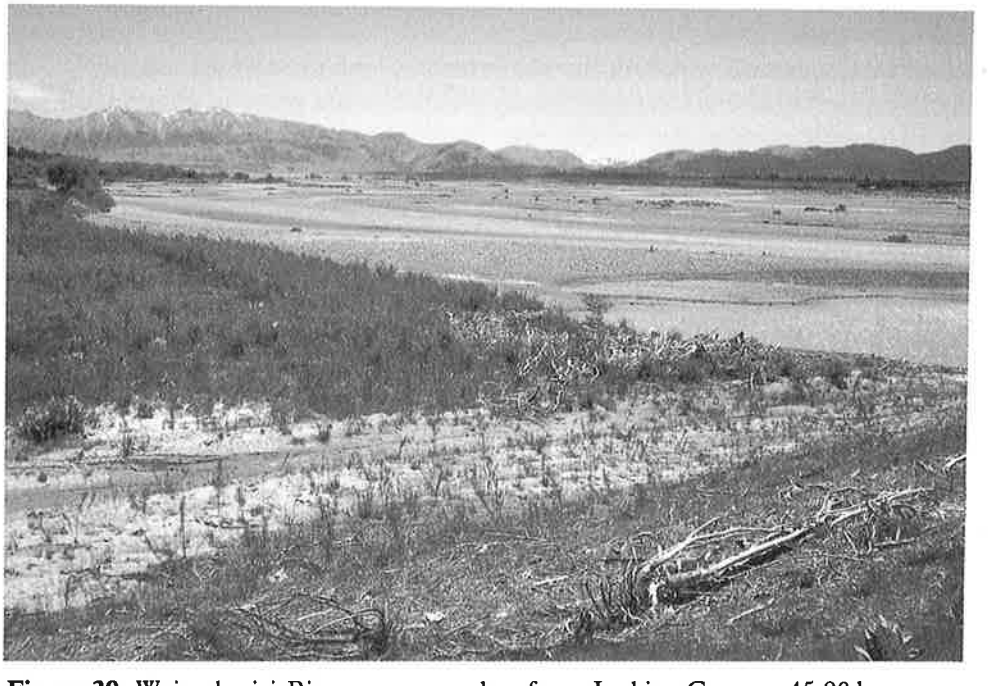


Figure 39: Waimakariri River upper reaches from Jenkins Groyne, 45.90 km. (R. Blakely, MWD)

Figure 40: Willow and poplar plantings along Kimberley Cliffs, upper reaches of the Waimakariri River with Torlesse Mountains in background; 1983. (R. Blakely, MWD)

The landscape in the middle reaches (reaches 3 to 5) has two distinct characters. The first is the open expanse of gravel riverbed and braided channel system, which has undergone only minor changes as a result of river control works. The principal changes have been the development of stable, partly tree-covered bermlands on the south bank between Miners Groyne and the Crossbank, while on the north bank, plantations of willow, poplar, and *Pinus radiata* have replaced the bare eroding banks which existed prior to about 1930. In general the views in both directions are still rather featureless, except for a distant view of the Torlesse Range in the upstream direction (Figure 41). The second area, the riparian zone which includes McLeans Island and other former river channel areas downstream from Halkett Groyne, has undergone major land use changes, i.e., from open riverbed and scrub to developed grasslands, managed pine plantations and recreational areas (Figures 42 and 43). All of these landscape changes are the direct result of river control works and the flood protection afforded by them. The overall trend is towards an increasingly diverse and stable landscape.

The riverscape in reaches 1 and 2 has changed from an open network of relatively narrow channels winding through grassland and swamp, through a semi-braided state to a single thread channel which is increasingly confined by rock work and dense willow and poplar bank protection. The open gravel riverbed, on which excavation machinery and gravel stockpiles are visible, gives way downstream to a deep, sand-silt bed channel (Figure 44).

The river mouth has also undergone major changes in response to river control works, particularly the control of the location of the mouth at the northern end of Brooklands Lagoon. Old photographs show the mouth as a broad expanse of water and shifting bars with little vegetation (Figure 45A). The landscape is still generally open (Figure 45B), with views

Figure 41: Waimakariri River middle reaches, Dixons Bay on the north bank; looking upstream from about 20 km. (A. C. Norton, NCCB)

Figure 42: Riparian land, McLeans Island river control works and forestry developments, 1983 (Ross-Weedons Road in middle ground). (R. Blakely, MWD)

Figure 43: McLeans Island Golf Course, protected by Waimakariri River stopbanks since 1968. (A. C. Norton, NCCB)

A: 1930 (NCCB)

B: 1983 (R. Blakely, MWD).

B: 1983 (R. Blakely, MWD).

Figure 44: The lower reaches of the Waimakariri River, Wrights Cut upstream of the Old Highway Bridge.

A: 1940 (NCCB)

B: 1983 (R. Blakely, MWD)

Figure 45: Waimakariri River Mouth.

to the sea and the Lagoon, but rock bank protection, planting of pine trees on the north bank and stabilisation of sand dunes with marram grass have tended to create a more confined but varied landscape.

The river control works have thus transformed the "desert-like" landscape confronting the early settlers into a wooded, relatively sheltered environment which contains a wider variety of vegetation and landscape types. Although uniform plantings along certain channels may have decreased visual quality there, this change appears to have been outweighed by improvements in the riparian zone due to the increased variety of land uses (Norton, 1983).

5.7 Recreation

The main recreational pursuits prior to 1930 were fishing, picnicking and swimming, mainly in the tidal reaches (estuary and mouth), with trout fishing and eeling in the tributary side streams of the lower reaches. Game shooting was also popular. Little use was made of the middle and upper reaches except by the more enthusiastic nature lovers and fishermen. In recent years there has been a general trend toward increased involvement in recreational activity as a result of increased mobility, leisure time and personal affluence. As New Zealand society has become more urbanised the value of a large, publicly owned, semi-wilderness environment close to Christchurch has increased (Reid and Poynter, 1982; Norton, 1983). This is reflected in the increased variety and intensity of recreational usage of the Waimakariri River.

Fishing is dominated by angling at the river mouth (Figure 46A), with lesser but still significant use made of the upstream reaches (Figure 46B). A general improvement in fish habitat and road access associated with the control scheme have improved angling opportunities, and have contributed to a marked increase in angling activity since about 1976 (C. Hardie, pers. comm.). Present use is estimated to be more than 100,000 angler visits per year, the highest for any South Island river (Teirney *et al.*, 1982). However, the benefit from stabilised pools along the banks has been offset by snagging problems caused by willow trees which mean that anglers often choose to fish in mid-channel away from such obstructions. Elimination of flood flows from the North and South Branches has improved angling and increased their level of use.

Picnicking and swimming occur at three levels of development. The first are formal developed areas, the main areas being the Groynes and McLeans Island. The Groynes picnic area on the former south bank includes deep (though cold) spring-fed pools for swimming and boating, a walkway, and a pond for model boats. McLeans Island is zoned as a 'recreation' area in the Paparua County and in the Waimairi District Planning Schemes, and contains 600 ha of land leased to 13 clubs and organisations. Both areas are dependent for their existence on the river control scheme, through elimination of flood flows and stabilisation of the old riverbed. In addition, tree planting (originally for bank protection) provides shelter, shade, and visual enhancement. The second are informal, partly developed areas, examples of which are the Eyrewell State Forest picnic and camping ground and the Willows area at the Paparua County water intake. The third are undeveloped areas where improved road and track access to the riparian zones have made available many informal picnic sites (Figure 47), and control works have led to the development of stable, deep pools which are used for swimming. Again, tree planting has enhanced the old riverbed by providing shelter, shade and visual variety (Figure 48).

Pleasure driving has increased as access to the river banks has improved and as tree planting and stabilisation of the riparian zone have made the riverscape more attractive. This form of recreation is confined, at present, mainly to the lower reaches of the river. Along the south bank from Crossbank to the Old Highway Bridge there are 34 vehicular access points to the river, and about 100 km of tracks maintained by NCCB, which are open to the public.

A: Angling at the River Mouth (C. Hardy, MAF)

B: at Jenkins Groyne (R. Blakely, MWD)

Figure 46: Angling on the Waimakariri River.

Boating, including jet boating, sailing, canoeing and rafting is increasing, particularly in the lower reaches. Sailing occurs at the river mouth and Stewarts Gully. Jet boating is popular between the Motorway Bridge and the main Gorge, with heavy use being made of the reach from the bridge to Crossbank. Rafting and canoeing are becoming very popular, particularly in the upper reach down to Thompsons Road (Egarr and Egarr, 1982) and raft racing is a frequent use of the river between Crossbank and the Motorway Bridge. Consequently, on summer weekends, there is a growing conflict of use between jet boaters, rafters, canoeists, fishermen and swimmers in this lower, easily accessible reach.

The development of a single braided channel across the foot of the fan has probably improved the river for boating, compared to its natural state, but the complex network of channels still challenges the skill of jet boaters, canoeists, and rafters. For example, passage problems still exist during low flow periods, particularly over riffles, and the river training works have also increased the hazards for boating, particularly from over-hanging trees and submerged rockwork and pile retards.

Figure 47: An informal picnic area on the south bank of the Waimakariri River, downstream from crossbank. (A. C. Norton: NCCB)

Stabilisation of the tidal reach has improved the security of yacht clubs at the river mouth and Stewarts Gully, and by stabilising Brooklands Lagoon the control works have facilitated its use by small boats and water-skiers.

Trail bikes and four-wheel drive vehicles are making increasing use of the riparian zone mainly because of improved access provided by the network of tracks and roads along the river, and the variety of terrain and trail experience provided by stopbanking and afforestation.

Damage to stopbanks from trail bike tracks is a widespread problem as is the disturbance to picnickers caused by their noise and dust.

Some areas of semi-wilderness suitable for trail bikes are being developed for other uses, such as McLeans Island and picnic areas along the south bank, but there are still large areas available to trail bikes away from such development, e.g., upstream of Crossbank.

Game shooting is a common activity in the wetland areas of the riparian zone. Wetland areas have become less extensive as a result of river control work, and opportunity for duck shooting has declined since 1850. Levels of use are unknown, but use is made of most remaining wetland areas along the full length of the river. There are significant areas of land in the upper reaches that are populated by rabbits and hares, but the areas of semi-wilderness and scrub in the middle and lower reaches have declined markedly as a result of river control (Figure 33).

Community groups and clubs using the McLeans Island recreational area include golf clubs, a rifle club, steam engine preservation society, vintage car club, caravan camping club, naturalists club, horse society, kennel club and wildlife park. New uses for land in McLeans Island continue to develop as access and the landscape are improved. The McLeans Island area was originally part of the South Branch natural flood channel system and was subject to frequent flooding. After the construction of the present McLeans stopbank in the 1960's, protection was given, up to the scheme's 100 year design flood. The present extensive development of recreational uses has evolved in response to this flood protection (Norton, 1983).

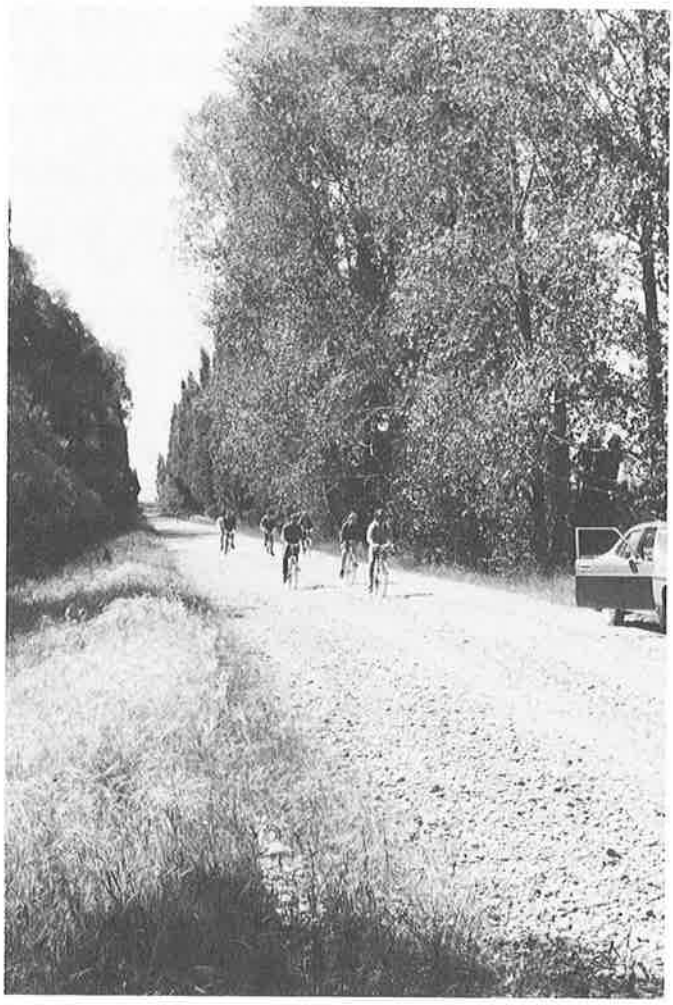


Figure 48: Cycling on the crossbank stopbank system, Waimakariri River. (A. C. Norton)

As an outdoor experience the Waimakariri provides a peaceful, semi-wild environment for walking, running, camping, cycling, outdoor education, bird watching and photography, or simply a place in which to experience the natural beauty of the riverscape. Although this use is not easily defined, it is believed to have increased markedly over the last 10 years. Other than the coastal areas, the Waimakariri River is the only readily accessible large area of semi-wild public land within 30 minutes drive of Christchurch (Reid and Poynter, 1982).

The river control scheme has enhanced the river's value for outdoor experience by improving access, providing viewpoints such as groyne heads, and enhancing the visual quality of the landscape, particularly through the tree planting programme. A good example of this is the Kaiapoi Walkway which follows the north bank stopbank from Kaiapoi to the mouth and provides an opportunity for urban dwellers to walk easily through an area of rural, semi-developed country. On the other hand, increasing development and use have reduced the quality of the outdoor experience for those who seek quiet and solitude. Nevertheless, large areas of riverbed and the riparian zone still remain unvisited by more than a few people for much of the year, and the NCCB policy of not confining the river further will maintain an extensive semi-wild area.

Summary of the effects of river control works on recreation

The river control programme has clearly had an influence, by creating new recreational environments or improving the suitability of others. The main beneficial effects of river control have been:

(1) improved public access;
(2) protection of the McLeans Island area and the South Branch system from flood overflows;
(3) stabilisation of the lower reaches, mouth and lagoon;
(4) constriction of the middle reaches, and concentration of the flow into a single (though braided) channel system;
(5) creation of local environments suitable for recreation, such as deep pools along banks for swimming, or woodland clearings for picnicking;
(6) enhancement of the visual quality of the riverscape by tree planting and reduction of the area of unstable, flood-prone riparian zone.

There have also been certain detrimental effects:

(1) the flood control scheme has permitted development of more land for agriculture, which has reduced the area of semi-wilderness land for hunting, etc.;
(2) improved access has increased conflicts between user groups, particularly where vehicular travel is concerned, and has also led to widespread littering and rubbish dumping;
(3) the landscape has become increasingly artificial, i.e., it bears little resemblance to the original natural landscape which some would regard as having had intrinsic value.

Overall, Egarr and Egarr (1982) rated the Waimakariri's potential for recreational use as "exceptional" with "moderate" scenic value.

6 Discussion and Conclusions

The Waimakariri River and its riparian lands have a number of functions and provide a number of valuable resources. They:

(1) convey flood waters and low flows to the sea, provide temporary storage, and provide a surface water resource;
(2) recharge groundwater, and support a groundwater resource;
(3) store and convey sediments, and provide a gravel resource;
(4) provide habitat for fish and wildlife;
(5) provide recreation opportunities;
(6) provide visual variety in the landscape;
(7) provide a source of timber;
(8) provide grazing for stock;
(9) have provided an area of land which is suitable for agricultural and urban development.

The river control scheme has, in some way, modified every one of these functions or resources, as has been discussed in preceding sections.

The salient conclusions of the preceding sections are as follows:

Hydraulics

(1) Partly in response to the depletion of the original vegetation cover, the natural character of the lower Waimakariri River changed from an entrenched channel at the head of its floodplain, leading to an anastomosing channel network flowing amongst forested islands and swamps, to a wide braided channel on the fan area of its floodplain with several flood channels diverging towards the swamps and spring-fed rivers at the margin of the fan. The river control works carried out since 1850 have changed the middle and lower reaches into a single, confined, wide braided channel which leads to an artificial, nearly straight channel from the toe of the fan to the sea.
(2) The mean annual volume of gravel transported in the lower reaches from the reaches upstream of Crossbank increased by 60% between the survey periods 1930–1955 and 1968–1981. Over half of this sediment is derived from channel and bank reworking in the upper and middle reaches.
(3) The supply of gravel to the lower reaches has probably been accelerated by the combination of the clearance of scrub and forest from riparian areas of the floodplain about A.D. 1000, and river control works increasingly confining floods to one floodway since about 1930. There is no clear evidence that clearance of large areas of forest in the upper catchment has affected sedimentation rates in the lower river.
(4) Assuming stopbanks do not fail by undermining, seepage or shear there are two reaches where floodway capacity is less than that required to pass the 100 year design flood. In these reaches, maximum flood recurrence intervals are close to 50 years. The most critical reach is at 12.47 km, with a 1978 maximum flood RI of 45 years, this location being the "weakest link in the chain" of stopbanks surveyed in the 1974–78 period.
(5) The mean value of stream power in the middle of lower reaches is 210 W/m^2 of active floodway when the river is flowing at its present 100 year design flood. Stream power is approximately constant between reaches, except for a short reach at Engelbrechts, where it is nearly double the average. At this point, the river's character changes markedly and there is a discontinuity in channel pattern.
(6) Stream power per square metre is now markedly higher than it was before river control works construction, gravel is being carried further downstream, and the river has moved its main locus of fan-building to the reach from about 14 km (where the channel slope begins to reduce) to Wrights Cut, where the stream power per square metre is less than half the average. Gravel must be extracted from the lower reaches of the river at a minimum rate of 150,000 m^3/year to limit further loss of flood capacity resulting from the continuing aggradation occurring at critical sections in these reaches.

Economics (1982 dollars)

(7) The costs and benefits of the scheme are summarised in Table 11. The total expenditure on river control to date has exceeded $100 million, and the capital value of the floodplain/fan, weighted for flood risk, is almost $900 million. Thus, for each dollar spent, $8.30 of floodplain assets have been protected from floods of up to 50 year RI (the present level of protection).

Table 11: A summary of data on river control expenditure, stream power, and floodplain values.

River control expenditure	Total Expenditure (1857–1981) Reaches 1–7	$\$107 \times 10^6$
	Reaches 2–7	$\$91 \times 10^6$
	Reaches 2–5	$\$85 \times 10^6$
Stream power	Main Stream Power (1982) at 100 year design flood (4300 m^3/s) : Reaches 2–5	210 W/m^2
Floodplain statistics	Weighted Capital Value of floodplain (1982)	$\$888 \times 10^6$
	Population of floodplain (1981)	244,105
	overall density	548/km^2
	urban density	1622/km^2
	rural density	78/km^2
	Floodplain areas: Total (excl. riverbeds/lagoons)	477.38 km^2
	urban/industrial	116.26 km^2
	class I and II agric. land	134.26 km^2
Costs and economic benefits	Floodplain C.V. at risk (weighted)/person (1982)	$36.40
	River Control Exp. per person (1857–81)	$438
	Estimated value of floodplain assets at risk per dollar of River Control Expenditure per person	$8.30
	Expenditure per ha of floodplain per yr[1]	$17.92

Note: 1 Average expenditure over period of river control works, 1857-1982

Floodplain Land Use

(8) The construction of river control works has encouraged major land use changes over the last 100 years. The main changes in reaches 1–5 have been:

(i) a 50% decrease in area of active riverbed from 1880 to 1982;

(ii) a 148% increase in area of developed pasture in the riparian zone and bermlands from 1932 to 1982, mainly resulting from a 90% decrease in the area of scrublands over this same period.

(9) River control works have decreased the probability of flood damage on the floodplain from approximately 1 year in 5 in about 1860 to approximately 1 in 50 in 1982. This decrease in apparent flood hazard has encouraged more intensive development of the floodplain, while at the same time increasing the potential flood damage resulting from breakout of a major flood.

Groundwater

(10) River control works, particularly since 1971, upstream and downstream of Halkett Groyne, have been at least partly responsible for a significant decrease in the quantity of water lost from the river in this reach.

The River Environment

(11) River control works and associated riparian and bermland development have had a major beneficial effect on the river landscape relative to its 1850's condition. Recreational opportunities have increased through the protection from floods of former riverbed areas. Recreation in riparian areas has increased, partly in response to the improved shelter and aesthetic values resulting from the extensive tree planting associated with the river control works.

(12) Wildlife habitat (fish cover and bermland nesting sites) has improved as a result of riparian and bermland plantings. The development of a single floodway has led to a reduction in wetland areas relative to the pre-river control conditions, and the stabilisation and protection of lowland streams from floods. Some of the benefits from

improved habitat for some birdlife have probably been lost as a result of increased recreational and forestry uses of the lower and middle reaches. The relatively uncontrolled and uninhabited upper reaches are the last large area suitable for the varied needs of fish and birdlife.

(13) The increase in the river's stream power in the middle and lower reaches, contributing to the frequent movement of sediments in the main river channel, has probably reduced some of the benefits afforded to fish by improved cover from stabilised banks, groyne head pools and backwaters.

River management implications

The first priority of the Waimakariri River control scheme is, of course, to provide protection against flooding for the floodplain/fan. The design flood has an RI of 100 years, but at present the scheme provides protection against floods up to an RI of about 50 years. This contrasts with a frequency of flooding of once every 5 years in the early years of European settlement.

Benefits of the control scheme are being reflected in more intense riparian land use. Flood protection has contributed to increases in population density, land values and capital values of the floodplain, and is allowing urban, agricultural and forestry interests a more secure development on land that was formerly intermittently active riverbed. The riverbed has also been developed for recreation in the last 15–20 years, with the provision of shelter, shade, access to water, and recreational facilities such as wildlife parks, golf courses, hobby clubs. A more diverse riverscape than existed before 1930 has also increased the opportunities for recreation.

The Mcleans Island area is an excellent example of how land use changes in the riparian floodplain zone have resulted from increased protection from floods, in this case by stopbank realignment in the late 1960's. Similarly, the development of "park-like" forestry plantations on former riverbed areas in reaches 4 and 5 (the middle fan zone) has encouraged greater use for recreation, grazing and forestry.

Although the control scheme's primary objective is flood alleviation, it is increasingly clear that local authorities, including the NCCB, are accepting the responsibility of managing the Waimakariri River and its riparian zone for multiple use. Liaison between local authorities in this area is exemplified by the Mcleans Island resource assessment (Norton, 1983), which illustrates land use policies established by the Paparua and Eyre County Councils, in co-operation with the NCCB.

From this study of riparian land use changes, it is apparent that the main activities (apart from on Mcleans Island) have been the planting of banks with willows, afforestation of old riverbed areas and the small areas of the narrow floodplains in the upper reaches with *Pinus radiata*, and the clearance of scrub in the lower reaches (downstream from the Crossbank) to open up areas of fertile, well drained soils for horticulture and cash cropping. Greater use of riparian land in the upper reaches (32 to 57 km) is likely to create long-term river control problems; only a narrow strip of floodplain is available for agriculture, requiring long lengths of bank protection works for relatively small areas of land. The management of the upper, relatively unmodified reaches of the river is critical to the management of sedimentation in the lower reaches. They are also the only remaining large area of riverbed which provides good wetland areas for wildlife, especially the three endemic species dependent upon such areas for their survival (the wrybill plover, black billed gull and black fronted tern).

Future management

The present multiple use river management policy has provided a sound basis from which to integrate the needs of river control with the wildlife and recreational demands on the river. From consideration of the findings of this report, we draw attention to the possibilities concerning flooding, erosion and sedimentation, while preserving or enhancing opportunities for recreation and wildlife.

Reaches 5, 6, and 7 (23–57 km): It does not appear practicable or desirable to significantly reduce sediment supply rates to the lower reaches by channel works upstream of Halkett Groyne. Any further confinement in the middle and upper reaches by a combination of planting and groyne construction could well accelerate the existing degradation trends of the active riverbed. However, continued protection of bermlands, terraces and banks by planting of vegetative screens, armoured with groynes where necessary, is essential to the long-term maintenance of the present river regime. An open planting policy on bermlands is suggested, whereby flood flows may move through semi-forested berms with a minimum of resistance. In this way, floods may be encouraged to deposit gravels in the main active channel area, as silt laden flows spread through adjoining bermlands. Permeability can be controlled by pruning, thinning and undergrazing, with tree species varied according to their suitability to soil type. This system, already in operation in certain berm areas, would effectively reduce the stream power available to transport sediment into the lower reaches; the sediment would be deposited in the present degrading reach where channel capacities greatly exceed design requirements. Soil depth would increase as a result of flows spreading through the bermlands and lead to a potentially more productive floodplain. The natural braided character of the river would also be preserved for wildlife and recreation.

Reaches 1, 2, 3 and 4 (23 km to the sea): From a detailed investigation of river flow patterns and stream power variability in reaches 2–4, a floodway alignment can be designed to marry the two conflicting channel patterns intersecting near Engelbrechts (11–12 km). This would have an open meander pattern, with a gradually decreasing wave length and amplitude as channel slopes decrease and flow depths increase. This alignment would spread flood flows in the middle and upper reaches of the former alluvial fan, with a gradual confinement to a semi-braided, gently meandering channel in the lower reaches.

As part of this design approach, assuming present aggradation trends continue in the lower reaches, a minimum gravel extraction rate of 150,000 m^3/year will be required, subject to regular review.

A secondary, but important part of the "bio-engineering" approach (Schiechtl, 1980) to the long-term management of the Waimakariri River concerns 'environmental enhancement'. Recent experimental and demonstration plantings of new, improved tree and shrub species (by Ministry of Works and Development) have already shown potential to further enhance the river environment through the use of increased diversity of species. With the initial plant colonisation of the once largely bare floodplain nearly complete, the microclimate now exists for the establishment of a wider range of plant species, which could further enhance the semi-wilderness values of the area. In some areas, small pockets of remnant native vegetation can be enriched and protected. Overall, the floodplain/fan will require careful and sensitive management because the ecosystems developing on the bermlands are still poorly understood and in a state of evolution.

This study helps to clarify the relationships among the water and soil resources of the Lower Waimakariri River and and its floodplains, the biological systems dependent upon them, and the recreational resources created through the development of the present river regime.

River control works have enhanced the use of the river and its associated bermlands for recreation and wildlife, and improved the level of flood protection of the rivers' increasingly intensively developed floodplain. River behaviour in the upper and middle reaches will require careful management to safeguard flood capacities in the lower reaches and to maintain the present high values of the wildlife habitat and recreational opportunity. With the increasing public demand for the multiple use of rivers for irrigation, high quality water supply, wildlife and recreation, the Waimakariri River provides an excellent opportunity for the sharing of its resources amongst the widest possible range of users. However, minimisation of the risk from flooding, erosion and sedimentation must remain the most important consideration in all future management decisions. The river may appear to have been "civilised" (*Lyttelton Times,* 1859) but a major flood in its lower reaches must now dissipate

significantly greater stream power for each square metre of its channel than before river control works began in the 1850's. In 125 years, the river has been directed to follow one path to the sea. This has required a major expenditure on control works, which although successful to date, can be only truly evaluated by the next major flood.

Methodology

As noted in the introduction, this study of the Waimakariri River was intended to be the first of 15–20 which, together, would provide insight into the impacts of river control works on different types of rivers.

The type of data to be collected and their form of presentation were progressively refined during the study, so a formal comparison of methodologies is not possible. We suggest, however, that the information assembled enables assessment, with a high degree of confidence, of the relationship between river control work, the physical character of the river, and its environment as habitat for animals, fish and people. In particular, we note that the concept of stream power has proved a very valuable index with which to evaluate the impacts and effectiveness of river control, and to identify locations at which further control work may be necessary.

We also note the desirability of adopting a multi-disciplinary approach to further studies of this type. Undeniably, the primary reason for river control works is to increase channel stability and/or to reduce flood risk, and the effectiveness of a control scheme may be analysed rather precisely using quantitative procedures (although, in passing, one might note that many schemes have not been subject to such analysis). However, many impacts of river control works relate to river use by humans, fish and wildlife. Such uses, and the impacts upon them, are increasingly important to the public, but in many cases are difficult or impossible to quantify. They cannot be neglected, however, and resort must be made to inclusion of appropriate "experts" in the study team, to ensure that nothing is missed.

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Appendix 1

Hydraulic Data for the Waimakariri River at Selected Cross-sections, 1929–1978

Introduction

All data in this Appendix (Tables A1.1 and A1.2) have been measured and estimated from original NCCB cross-section survey records and from aerial photograph interpretation. Slope was calculated using the method described in the text (Section 4).

The date of survey for each section is given where possible, otherwise the year only is given.

Table A1.1

Roughness values ("N") are listed as N_s for bermland on the true left of the riverbed, with subscripts 1, 2 etc. for each subsection. N_c is the roughness value for the main or "central" channel while N_L subscript 1, 2 etc. is that of the true right bermland of the riverbed. These codes correspond to the backwater calculation roughness values used by the "Rivers" backwater computer program.

Widths (W_1) and areas (A_1) are listed for each roughness value and are grouped into true left berm (T. L. berm), main channel, and the true right berm (T. R. berm).

For the 1929 survey values of width, area and flow for sections 6.03, 6.44 and 6.84 km have been estimated only approximately because Wrights Cut was being constructed in this reach at that time.

Table A1.2

Flow was calculated from data for channel area, slope, width and roughness listed in Table A1.1 using the formula $Q = A^{1.66}\ S^{0.5}\ W^{-1.66}\ N^{-1}$. Stream power was calculated using values for flow (calculated as above), channel slope and width (listed in Table A1.1), using the formula $W = Q.S.\ w^{-1}$ as described in Section 4.

Figures 20, 21, 24, 25 and 26 summarise these data in the text (Section 4.1).

Table A1.1: Hydraulic data for Waimakariri River cross-sections (at bankfull or design flow)

Sect. (km)	Date of Survey	Bank-full (B.F.) Water Level (m)	Roughness Values "N"					Widths (m) and Areas (m^2) for Each Subsection by Roughness																Widths (m)			Slope
								N_s:T.L. BERM						N_c:MAIN CHANNEL				N_L:T.R BERM						*1 W_a	*2 W_t	*3 W_e	
			N_{s1}	N_{s2}	N_c	N_{L1}	N_{L2}	N_{s1}		N_{s2}		N_{s3}		N_{c1}		N_{c2}		N_{L1}		N_{L2}		N_{L3}					
								W_1	A_1	W_2	A_2	W_3	A_3	W_1	A_1	W_2	A_2	W_1	A_1	W_2	A_2	W_3	A_3				
REACH 2																											
6.03	Jan '32	–	.05	.05	.03	.05	–	5	2	21	18	67	75	6	9	4	5	39	32	–	–	–	–	67	142		.00149
	Apr '55	–	.125	.05	.03	.05	.125	88	81	16	15	–	–	143	334	–	–	77	42	40	35	–	–	143	364		.00207
	Dec '77	4.2	.125	.05	.03	.05	–	–	–	–	–	–	–	185	426	–	–	–	–	–	–	–	–	185			.00214
	DESIGN	7.9	.125	.05	.03	.05	–	85	310	91	293	–	–	185	1104	–	–	186	638	–	–	–	–	185	547	370	.00214
6.44	Jan '32	4.3	N cut = .03		N BERM = .05																			149	460		.00167
	Apr '55	6.1	.125	.05	.03	.05	.125	116	127	148	105	–	–	88	300	–	–	118	128	97	146	–	–	88	567		.00098
	Dec '77	5.3	–	.05	.03	–	–	–	–	53	29	–	–	151	447	–	–	–	–	–	–	–	–	151	204		.00120
	DESIGN	8.4	.125	.05	.03	.05	.125	80	266	139	448	–	–	151	927	–	–	115	329	79	307	–	–	151	564	390	.00120
6.84	Jan '32	4.4	N cut = .08		N BERM = .05																			116	182		.00204
	Apr '55	6.8	.125	.05	.03	.05	.125	77	64	97	109	–	–	232	725	–	–	176	215	–	–	–		232	582		.00065
	Dec '77	5.6	.125	.05	.03	.05	.125	–	–	–	–	–	–	274	631	–	–	9	8	15	12	–	–	1277	298		.00079
	DESIGN	9.1	.125	.05	.03	.05	.125	83	246	92	295	–	–	274	1589	–	–	9	43	19	77	104	349	274	581	400	.00079
7.64	Apr '29	6.8		.05	.03	.05		–	–	91	41	–	–	127	290	–	–	–	–	–	–	–	–	127	218		.00154
	May '55	7.4		.05	.03	.05		–	–	115	78	–	–	397	638	–	–	83	51	–	–	–	–	397	595		.00203
	Dec '77	7.3			.03	.05		–	–	–	–	–	–	349	786	–	–	59	30	–	–	–	–	349	408		.00214
	DESIGN	10.2	.125	.05	.03	.05	.125	67	229	51	144	–	–	349	1795	–	–	64	215	80	132	–	–	349	611	460	.00214
8.45	Apr '29	8.1			.03	.05		–	–	–	–	–	–	300	367	–	–	17	21	–	–	–	–	300	317		.00170
	Feb '55	9.4	.125					–	–	162	227	–	–	454	778	–	–	–	–	–	–	–	–	454	616		.00235
	'78	9.3	.125	.05	.03			159	189	102	78	–	–	354	767	–	–	–	–	–	–	–	–	354	615		.00242
	DESIGN	11.4	.125	.05	.03	.065	.125	164	531	102	292	–	–	354	1509	–	–	65	160	104	264	–	–	354	789	470	.00242
9.25	Apr '29	9.1	.125		.03			364	270	–	–	–	–	137	77	95	81	–	–	–	–	–	–	232	596		.00235
	Jun '55	11.4	.125	.05	.03	.05		262	437	250	239	–	–	301	783	–	–	78	64	–	–	–	–	301	891		.00215
	'78	10.4	.125		.03			178	111	–	–	–	–	343	557	–	–	–	–	–	–	–	–	343	521		.00229
	DESIGN	12.8	.125	.05	.03	.05		278	773	219	505	–	–	347	1381	–	–	83	158	–	–	–	–	347	927	486	.00229
10.06	Apr '29	11.1	.125	.125	.03	.05	.125	92	31	17	7	–	–	120	76	–	–	243	97	173	125	–	–	120	645		.00288
	Jun '55	12.1			.03	.05		–	–	–	–	–	–	493	449	–	–	258	177	–	–	–	–	493	751		.00248
	Jan '78	12.8	.125		.03	.05		79	37	–	–	–	–	540	762	–	–	243	262	–	–	–	–	540	862		.00287
	DESIGN	14.5	.125	.05	.03	.05		108	225	7	13	–	–	509	1673	–	–	285	763	–	–	–	–	509	909	500	.00287
10.86	'29	14.5		.05	.03			–	–	–	–	–	–	501	640	–	–	–	–	–	–	–	–	501	501		
	'55	14.5	.125	.05	.03			102	85	170	82	–	–	507	475	–	–	–	–	–	–	–	–	507	779		
	'78	14.8	.125		.03			293	161	–	–	–	–	391	353	–	–	–	–	–	–	–	–	391	684		.00324
	DESIGN	16.6	.125	.05	.03			187	444	236	490	–	–	410	1091	–	–	–	–	–	–	–	–	410	833	350	.00324
REACH 3																											
11.67	Apr '29	17.2			.03		–	–	–	–	–	–	–	676	932	–	–	–	–	–	–	–	–	676	676		.00321
	Jul '55	17.2			.03		.125	–	–	–	–	–	–	561	532	–	–	–	–	115	77	–	–	561	676		.00343
	Jan '78	17.5			.03		.125	–	–	–	–	–	–	798	764	–	–	–	–	290	400	–	–	798	1088		.00338
	DESIGN	18.9		.05	.03		.125	–	–	163	156	–	–	798	1705	–	–	–	–	292	780	–	–	798	1253	650	.00338
12.47	May '29	20.4			.03		.125	–	–	–	–	–	–	290	610	–	–	290	712	–	–	–	–	290	580		.00359
	Dec '55	20.4			.03		.125	–	–	–	–	–	–	290	374	–	–	290	610	–	–	–	–	290	580		.00356
	Jan '78	20.4			.03	.075	.125	–	–	–	–	–	–	630	511	–	–	300	230	390	596	–	–	630	1320		.00381
	DESIGN	21.1	.125		.03	.075	.125	55	26	–	–	–	–	685	1059	–	–	104	119	395	866	–	–	685	1239	730	.00381

Sect. (km)	Date of Survey	Bank-full (B.F.) Water Level (m)	Roughness Values "N"					Widths (m) and Areas (m²) for Each Subsection by Roughness														Widths (m)			Slope
								N_s:T.L. BERM						N_c:MAIN CHANNEL				N_L:T.R BERM							
								N_{s1}		N_{s2}		N_{s3}		N_{c1}		N_{c2}		N_{L1}		N_{L2}		N_{L3}		*1 W_a	*2 W_t	*3 W_e	
			N_{s1}	N_{s2}	N_c	N_{L1}	N_{L2}	W_1	A_1	W_2	A_2	W_3	A_3	W_1	A_1	W_2	A_2	W_1	A_1	W_2	A_2	W_3	A_3				
13.27	May '29	23.5			.03			–	–	–	–	–	–	517	1233	–	–	–	–	–	–	–	–	517	517		.00415
	Nov '55	23.5			.03			–	–	–	–	–	–	526	901	–	–	–	–	–	–	–	–	526	526		.00407
	Jan '78	23.4			.03	.05		–	–	–	–	–	–	554	503	–	–	143	48	–	–	–	–	544	697		.00389
	DESIGN	24.6	.125		.03	.05	.125	105	146	–	–	–	–	576	1190	–	–	143	223	140	141	–	–	576	964	680	.00389
14.08	May '29	26.1			.03			–	–	–	–	–	–	755	744	–	–	–	–	–	–	–	–	755	755		.00431
	Nov '55	26.1			.03			–	–	–	–	–	–	697	392	–	–	–	–	–	–	–	–	697	697		.00430
	Jan '78	26.1			.03			–	–	–	–	–	–	633	264	–	–	–	–	–	–	–	–	633	633		.00422
	DESIGN	28.0	.125		.03		.125	140	226	–	–	–	–	701	1533	–	–	–	–	165	240	–	–	701	1006	700	.00422
14.74	May '29	29.0			.03			–	–	–	–	–	–	871	631	–	–	–	–	–	–	–	–	871	871		.00470
	Nov '55	29.0			.03			–	–	–	–	–	–	913	1129	–	–	–	–	–	–	–	–	913	913		.00460
	'78	29.2			.03	.05		–	–	–	–	–	–	195	74	305	215	290	59	–	–	–	–	500	790		.00470
	DESIGN	33.6		.03	.03			–	–	–	–	94	227	214	585	640	1796	–	–	–	–	–	–	854	948	850	.00470
15.59	'29	33.5			.03			–	–	–	–	–	–	1068	727	–	–	–	–	–	–	–	–	1068	1068		.00467
	'55	33.5			.03			–	–	–	–	–	–	1095	635	–	–	–	–	–	–	–	–	1095	1095		.00459
	Jan '78	33.5			.03			–	–	–	–	–	–	295	250	530	381	–	–	–	–	–	–	825	825		.00454
	DESIGN	34.8		.07	.03			–	–	273	372	–	–	295	620	530	1064	–	–	–	–	–	–	825	1098	900	.00454
16.69	Jun '29	38.0			.03			–	–	–	–	–	–	1116	605	–	–	–	–	–	–	–	–	1116	1116		.00473
	Dec '55	38.0			.03			–	–	–	–	–	–	1170	463	–	–	–	–	–	–	–	–	1170	1170		.00467
	Jan '78	38.0		.05	.03			–	–	380	161	–	–	700	343	–	–	–	–	–	–	–	–	700	1080		.00452
	DESIGN	39.5		.05	.03		.125	–	–	380	742	–	–	700	1389	–	–	–	–	160	274	–	–	700	1240	1050	.00452
REACH 4																											
17.81	'29	43.3			.03			–	–	–	–	–	–	–	1442	997	–	–	–	–	–	–	–	1442	1442		.00543
	'55	43.8			.03			–	–	–	–	–	–	–	1442	759	–	–	–	–	–	–	–	1442	1442		.0050
	'78	43.8			.03			–	–	–	–	–	–	–	1024	780	–	–	–	–	–	–	–	1024	1024		.00491
	DESIGN	45.3			.03			–	–	–	–	–	–	–	1060	2442	–	–	–	–	–	–	–	1060	1060	1050	.00491
19.93	'29	54.0			.03			–	–	–	–	–	–	–	894	375	–	–	–	–	–	–	–	894	894		.00490
	'55	54.0			.03			–	–	–	–	–	–	–	1061	382	–	–	–	–	–	–	–	1061	1061		.00490
	'78	54.0			.03			–	–	–	–	–	–	–	1280	396	–	–	–	–	–	–	–	1280	1280		.00490
	DESIGN	55.5			.03			–	–	–	–	–	–	–	1280	1500	–	–	–	–	–	–	–	1280	1280	1120	.00490
22.27	'30	65.3			.03			–	–	–	–	–	–	866	401	421	210	–	–	–	–	–	–	866	1287		.00502
	'55	65.3			.03	.03		–	–	–	–	–	–	866	569	–	–	421	170	–	–	–	–	1287	1287		.00489
	'79	65.3			.03	.05		–	–	–	–	–	–	950	600	–	–	328	144	–	–	–	–	950	1278		.00489
	DESIGN	66.5			.03	.05		–	–	–	–	–	–	1100	1959	–	–	328	570	–	–	–	–	1100	1428	1350	.00489
REACH 5																											
24.43	'30	76.2			.03			–	–	–	–	–	–	414	395	–	–	–	–	–	–	–	–	414	414		.00518
	'56	76.2			.03			–	–	–	–	–	–	661	927	–	–	–	–	–	–	–	–	661	661		.00509
	Dec '79				.03			–	–	–	–	–	–	942	608	–	–	–	–	–	–	–	–	942	942		.00509
	DESIGN	79.9			.03			–	–	–	–	–	–	1223	2538	–	–	–	–	–	–	–	–	1223	1223	1220	.00509
26.96	Jul '30	89.5			.03			–	–	–	–	–	–	863	385	–	–	–	–	–	–	–	–	863	863		.00527
	Apr '56	89.5			.03			–	–	–	–	–	–	1128	790	–	–	–	–	–	–	–	–	1128	1128		.00538
	Jan '80	89.5			.03			–	–	–	–	–	–	1259	1041	–	–	–	–	–	–	–	–	1259	1259		.00538
	DESIGN				.03			–	–	–	–	–	–	1374	2692	–	–	–	–	–	–	–	–	1374	1374	1300	.00538

Sect. (km)	Date of Survey	Bank-full (B.F.) Water Level (m)	Roughness Values "N"					Widths (m) and Areas (m^2) for Each Subsection by Roughness														Widths (m)			Slope
								N_s:T.L. BERM						N_c:MAIN CHANNEL				N_L:T.R BERM						*1 W_a	*2 W_t	*3 W_e	
			N_{s1}	N_{s2}	N_c	N_{L1}	N_{L2}	N_{s1}		N_{s2}		N_{s3}		N_{c1}		N_{c2}		N_{L1}		N_{L2}		N_{L3}					
								W_1	A_1	W_2	A_2	W_3	A_3	W_1	A_1	W_2	A_2	W_1	A_1	W_2	A_2	W_3	A_3				
29.37	Jul '30	103.1			.03									1384	1195									1384	1384		.00516
	May '56	103.1			.03									1284	1160									1284	1284		.00528
	Feb '80	103.1			.03									738	1067	279	171							1017	1017		.00528
	DESIGN	104.8			.03									1377	2989									1377	1377	1370	.00528
31.38	Aug '30	113.0		.06	.03			-	-	409	298	-	-	915	748	-	-	-	-	-	-	-	-	915	1324		.00478
	Nov '56	113.0		.06	.03			-	-	409	241	-	-	960	665	-	-	-	-	-	-	-	-	960	1369		.00482
	Jan '80	113.0		.06	.03			-	-	300	171	-	-	1108	892	-	-	-	-	-	-	-	-	1108	1408		.00482
	DESIGN	114.5		.06	.03			-	-	300	618	-	-	1108	2545	-	-	-	-	-	-	-	-	1108	1408	700	.00482
REACH 6																											
32.19	Aug '30	117.0			.03			-	-	-	-	-	-	960	990	-	-	-	-	-	-	-	-	960	960		.00493
	Aug '56	117.0			.03			-	-	-	-	-	-	860	724	-	-	-	-	-	-	-	-	860	860		.00495
	Jan '80	117.0			.03			-	-	-	-	-	-	770	789	-	-	-	-	-	-	-	-	770	770		.00495
	DESIGN	119.5		.06	.03			-	-	430	1152	-	-	770	2643	-	-	-	-	-	-	-	-	770	1200	700	.00495
35.41	Dec '30	133.5			.03			-	-	-	-	-	-	1403	1395	-	-	-	-	-	-	-	-	1403	1403		.00537
	Jan '57	133.5			.03			-	-	-	-	-	-	1387	1299	-	-	-	-	-	-	-	-	1387	1403		.00538
	Jan '75	133.5			.03			-	-	-	-	-	-	1414	1450	-	-	-	-	-	-	-	-	1414	1414	1200	.00538
38.62	Mar '32	151.0			.03			-	-	-	-	-	-	1530	1211	-	-	-	-	-	-	-	-	153-	1530		.00562
	Jan '57	151.0			.03			-	-	-	-	-	-	1608	953	-	-	-	-	-	-	-	-	1608	1608		.00564
	Dec '74	151.0			.03			-	-	-	-	-	-	968	693	608	228	-	-	-	-	-	-	1576	1576	1500	.00564
41.84	Mar '32	169.3			.03			-	-	-	-	-	-	-	1094	1125	-	-	-	-	-	-	-	-	1094	1094	.00529
	Jan '57	169.3			.03			-	-	-	-	-	-	1128	941	-	-	-	-	-	-	-	-	1128	1128		.00526
	Dec '74	169.3			.03	.06		-	-	-	-	-	-	1133	863	-	-	193	163	-	-	-	-	1133	1326	1400	.00526
REACH 7																											
43.45	Mar '32	177.0			.08	.03		-	-	427	247	-	-	1043	887	-	-	-	-	-	-	-	-	1043	1470		.00490
	Nov '56	177.0			.08	.03		-	-	427	331	-	-	963	545	-	-	-	-	-	-	-	-	963	1390		.00490
	Feb '75	177.0			.08	.03		-	-	466	186	-	-	1022	673	-	-	-	-	-	-	-	-	1022	1488	1000	.00490
45.06	Mar '32	185.5			.08	.03		-	-	525	459	-	-	1067	1554	-	-	-	-	-	-	-	-	1067	1592		.00525
	Feb '57	185.5			.08	.03		-	-	525	397	-	-	1067	1055	-	-	-	-	-	-	-	-	1067	1592		.00525
	Jan '75	185.5			.10	.03		-	-	303	153	-	-	1310	1125	-	-	-	-	-	-	-	-	1310	1613	1300	.00525
48.28	Dec '56	203.0			.08	.03		-	-	533	226	-	-	661	766	-	-	-	-	-	-	-	-	661	1194		.00522
	Jan '75	203.0			.08	.03		-	-	295	231	-	-	-	-	-	-	-	-	-	-	-	-	1037	1332	1300	.00522
54.21	Sep '33	232.5				.03		-	-	-	-	-	-	1139	879	-	-	-	-	-	-	-	-	1139	1139		.00480
	Sep '57	232.5				.03		-	-	-	-	-	-	1227	600	-	-	-	-	-	-	-	-	1227	1227		.00480
	Jan '75	232.5				.03		-	-	-	-	-	-	1047	824	-	-	-	-	-	-	-	-	1047	1047	1000	.00480

NOTES: *[1]Active width is width of bed occupied by bankful flow as interpreted from cross-sections.

*[2]Total width is the width occupied by flow including main active channel, and vegetated berms.

*[3]"Effective width" is the width occupied by the 100 year design flood. It is based on aerial photograph interpretation and excludes flow in trees, dense scrub, embayments or other constrictions, i.e., the unrestricted floodway width.

Table A1.2: Flow and stream power data for Waimakairiri River.

Section (km)	Date of Survey	Bankfull-BF or Design-DES	Flow (m^3/s)						Stream Power (W/m^2)		
			T.L. BERM		Main Channel	T.R. BERM		Total Flow	Main Channel	Total Flow	100 Year Flood Over Eff. Width
			Trees	Berm		Trees	Berm				
6.03	19.1.32	BF	9.5		94.9	10.8		115.2	21.1	12.1	
	6.4.55	BF	27.5	12.1	866	11.8	25.5	942.9	125.3	53.6	
	15.12.77	BF			1139			1139	131.7	131.8	
		DES	265	582	5535	1327		7709	640.3	301.6	251
6.44	13.1.32	BF			Wrights Cut			364	18.3	11.0	
	7.4.55	BF	33	52	698	48	85	916	76.8	15.8	
	15.12.77	BF	33		1043			1076	82.8	63.2	
		DES	160	669	3499	207	454	4989	272.6	106.1	133
6.84	12.1.32	BF			Wrights Cut			161.2	26.0	18.1	
	12.4.55	BF	36	189	1304	398		1927	36.4	21.3	
	20.12.77	BF			1021	8	13	1042	29.3	27.4	
		DES	111.9	361	4733	246	160	5612.9	137.5	76.9	86
7.64	12.4.29	BF	19		647		666	78.4	47.0		
	19.5.55	BF	54		1304	33		1391	667	47.5	
	21.12.77	BF			2076	17		2093	127.9	110.3	
		DES	187	265	8177	68	443	9140	502.8	321.0	203
8.45	8.4.29	BF			568	18		586	32.2	31.4	
	14.2.55	BF	109.5		1791			1900.5	92.7	72.4	
	1.78	BF	83	63	2088			2234	142.7	87.9	
		DES	453	572	6419	190	217	7851	438.8	240.8	225
9.25	12.4.29	BF	85		201			286	20.4	11.3	
	20.6.55	BF	225	215	2264	52		2756	161.7	66.5	
	1.78	BF	98		1218			1316	813	57.8	
		DES	581	836	5482	229		7128	361.7	223.0	200
10.06	16.4.29	BF	6.4	1.6	99	43	57	207	23.1	9.2	
	13.6.55	BF			697	137		834	35.0	27.5	
	1.78	BF	9.5		1708	294		2011.5	90.8	67.0	
		DES	155	21	6544	1562		8282	369.0	261.5	250
10.86	22.4.29	BF			1432			1432	94.9	94.9	
	13.7.55	BF	34.6	58	864			956.6	56.6	41.2	
	9.1.78	BF	49		621			670	51.5	31.7	
		DES	351	904	3918			5173	309.6	201.2	403
11.67	24.4.29	BF			2175			2175	103	103	
	13.7.55	BF			1002	28		1030	61.2	52.3	
	9.1.78	BF			1436	230		1666	60.8	51.8	
		DES		187	5782	744		6713	245	186.9	226

Section (km)	Date of Survey	Bankfull-BF or Design-DES	Flow (m^3/s)						Stream Power (W/m^2)		
			T.L. BERM		Main Channel	T.R. BERM		Total Flow	Main Channel	Total Flow	100 Year Flood Over Eff. Width
			Trees	Berm		Trees	Berm				
12.47	1.5.29	BF			1990	617		2607	245	161	
	2.12.55	BF			879	476		1355	108	83	
	9.1.78	BF			920	391	25	1336	56	50	
		DES	7.8		2904	718	107	3736.6	161	115	227
13.27	2.5.29	BF			4699			4699	377	377	
	17.11.55	BF			2733			2733	211	211	
	9.1.78	BF			981		29	1010	69	56	
		DES			3993	51	374	4418	270	200	250
14.08	27.5.29	BF			1612			1612	92	92	
	21.11.55	BF			586			586	36	36	
	1.78	BF			319			319	21	21	
	1.78	DES	161		5563	140		5864	335	247	262
14.74	27.5.29	BF			1167			1167	63	63	
	21.11.55	BF			2936			2936	151	151	
	78	BF			526		28	554	49	33	
	78	DES		557	10705			11262		241	239
15.59	29	BF			1285			1285	56	56	
	55	BF			1001			1001	42	42	
	1.78	BF			1191			1191	65	65	
	1.78	DES		440	6058			6498	333	269	220
16.69	4.6.29	BF			926			926	39	39	
	14.12.55	BF			572			572	23	23	
	1.78	BF		123	480			603	31	25	
	1.78	DES		1152	4892		210	6254	316	264	187
17.81	.29	BF			1919			1919	72	72	
	.55	BF			1171			1171	40.6	40.6	
	.78	BF			1522			1522	73	73	
	.78	DES			9894			9894	458	458	203
19.93	.29	BF			493			493	27	27	
	.55	BF			454			454	21	21	
	.78	BF			426			426	16	16	
	.78	DES			3886			3886	149	149	191
22.27	.30	BF			883			883	34	34	
	.55	BF			1223			1223	46	46	
	.79	BF			1032	177		1149	53	44	
	.79	DES			6683	1148		7831	297	268	157
24.43	30	BF			918			918	111	111	
	56	BF			2755			2755	212	212	
	12.79	BF			1083			1083	58	58	
	12.79	DES			9772			9772	407	407	182
26.96	8.7.30	BF			547			547	33	33	
	16.4.56	BF			1526			1526	73	73	
	28.1.80	BF			2246			2246	96	96	
		DES			10259			10259	402	402	180
29.37	22.7.30	BF			2597			2597	97	97	
	7.5.56	BF			2627			2627	108	108	
	19.2.80	BF			2596			2596	187	187	
		DES			12074			12074	463	463	167

Section (km)	Date of Survey	Bankfull-BF or Design-DES	Flow (m^3/s)						Stream Power (W/m^2)		
			T.L. BERM		Main Channel	T.R. BERM		Total Flow	Main Channel	Total Flow	100 Year Flood Over Eff. Width
			Trees	Berm		Trees	Berm				
31.38	18.8.30	BF	278		1509			1787	79	64.5	
	20.11.56	BF	197		1207			1404	52	48	
	30.1.80	BF	136		1789			1925	78	66	
		DES	1152		10196			11348	443	388	300
32.19	3.8.30	BF			2364			2364	121	121	
	20.8.56	BF			1515			1515	87.2	87.2	
	21.1.80	BF			1880			1880	120.8	120.8	
		DES		2589	13988			16577	899	761	280
35.41	11.12.30	BF			3395			3395	130	130	
	23.1.57	BF			3041			3041	118	118	
	1.75	BF			3605			3605	137	137	195
38.62	8.3.32	BF			2593			2593	95.2	95.2	
	16.1.57	BF			1689			1689	59.2	59.2	
	12.74	BF			1690			1690	60.5	60.5	163
41.84	15.3.32	BF			2778			2778		134	
	15.1.57	BF			2018			2018		94	
	12.74	BF			3761		177	3938	174.6	156	163
43.45	18.3.32	BF		150	1860			2010	87.4	62.7	
	28.11.56	BF		244	874			1118	44.5	36.8	
	5.2.75	BF		88	1192			1280	57.1	42.1	213
45.06	22.3.32	BF		436	4739			5175	234	171	
	1.2.57	BF		299	2529			2828	124	93.2	
	1.75	BF		71	2457			2528	98	82	176
48.28	31.12.56	BF		116	2033			2149	160	93.9	
	1.75	BF		182	1383			1567	69.7	61.4	175
54.21	19.9.33	BF			1710			1710	72	72	
	20.9.57	BF			865			865	33.8	33.8	
	1.75	BF			1625			1625	74.5	74.5	208

Appendix 2

Wildlife of the Waimakariri River Prior to 1900

by S. MOORE

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The earliest well documented exploration of this area began in 1849 when Torlesse and Boys were employed by the Canterbury Association to survey the area north of the Waimakariri River. European visits prior to this appear to have been confined to the coastal area. This involved whalers and sealers setting up shore bases and occasional visits to the Kaiapoi Pa by some early settlers from Banks Peninsula.

Unfortunately these early surveyor/explorers, although recording their visits to the area and keeping diaries of their work, recorded little information on the wildlife of the region. One reason for the absence of useful information on wildlife species present on the riverbeds is that the safest river crossing for travellers between Christchurch and Oxford was in the lower reaches. Upstream, the channels were considered too unstable for safe river crossing. What was recorded tended to be accounts of wild pig, dogs and birds shot, mainly waterfowl and New Zealand pigeons.

The only areas that received closer scrutiny were the bush areas, mainly because timber was in demand (Rangiora and Harewood Bush), with the result that more is known about the wildlife in these areas than any other area in the region.

In order to provide a list of birds that most probably utilised this habitat during that period, information has been extrapolated from knowledge of wildlife usage in a similar habitat type in Canterbury today. However, certain reservations must be held due to our limited knowledge of the actual habitat quality, as this could have some bearing on the presence or absence of some species. Particular factors are:

(1) Continuity of the habitat.
(2) Richness in understorey flora.
(3) Age structure of the trees (the Canterbury Plains suffered major fires during the pre-European period). The absence of older trees with holes would greatly restrict the presence of hole-nesting birds.
(4) Manuka was apparently a dominant vegetative type along the north bank and if it formed a dense thicket with a close canopy cover, the presence of some species could be affected.

Taking all these factors into account, the bird species that could have been present in berm areas covered in forest are:

Silvereye, Rifleman, Tom Tit, New Zealand Quail, Morepork, Kingfisher, Weka, Fantail, Bellbird, Grey Warbler, Brown Creeper.

Species that could have been present in areas devoid of forest cover are:

New Zealand Quail, Weka, Pipit.

Species that would have been recorded in both areas because of their mobility are:

Harrier hawk, Falcon, Pigeon.

References

—from Public Library
"Torlesse Papers", P. Maling.
"Oxford—The First Hundred Years", O. A. Gillespie.
"Beyond the Waimakariri", D. N. Hawkins.

Appendix 3

The Impact of the Waimakariri River Control Scheme on the Fish Species of the River

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1 The Mainstem Waimakariri as an Environment for Fish

The waters of the Waimakariri—its high-country lakes, mountain and lowland, the estuary and lagoon—provide a variety of environments for several kinds of freshwater and marine fishes. The dominant environment is that provided by the flood-prone, unstable, alluvial, mainstem reach of the river traversing the Canterbury Plains.

Each time a fresh or flood spills down the mainstem thousands of tonnes of gravels, sand and silt are set in motion. When the flow subsides, the previous pattern of braided channels is changed, and reshaped by newly-formed gravel bars and sandbanks. Overnight the aquatic ecosystem is disrupted. Habitats that provided fish with shelter, food and growing space disappear, and have until the next flood to re-establish and endure.

Because the substrate moves continuously, diatoms and algae—the base of the aquatic food chain—maintain only a light microflora on the gravels for the invertebrate animals to feed upon (the invertebrates are, in turn, the source of food for most stream fishes). Only in lengthy periods of low, clear flow (sometimes in the winter, but more often in summer and autumn months) do the diatoms and algae grow more thickly, and form a visible covering on the stones along the channel margins and in the quieter-flowing stretches of the river bed.

By comparison with stable, gravel-bottomed streams, where plants flourish and there is a dense and varied invertebrate fauna (for example the present South Branch or the upper Kaiapoi River), the open braided channels of the Waimakariri mainstem have a variable, but usually low benthic fauna in terms of species diversity and numbers present. This has not been specifically studied in the Waimakariri, but recent studies in the similar Rakaia River (Sagar, in prep.) show such to be the case.

Given its unstable, and often violent nature, the mainstem Waimakariri is a harsh and limiting environment for fish, yet many native species are found in its varied habitats. Introduced trout and salmon have adapted to its ways, although with differing degrees of success.

2 Fish Species

Only a summary of the Waimakariri's fish species, and their life histories, is given here. Further details are contained in McDowall (1978).

The New Zealand freshwater fish fauna consists of less than 50 species. Fewer than 30 are native species; the remainder are fishes introduced since European settlement (Tables A3.1 and A3.2).

NATIVE SPECIES

In one respect the Waimakariri differs from the other major Canterbury Plains rivers in that it has a significant tidal estuary joined to a shallow coastal lagoon.

The nutrients present in estuary water, and the fine sediments of the bottom and tidal margins, sustain a much higher production of food organisms of greater species diversity than do the freshwater and unstable substrate of the mainstem river. Some of the fishes listed in Table A3.1 live and breed within the influence of the tide; others are freshwater stream fishes migrating to and from the sea at some stage of their life history. Several are marine fishes which enter the estuary seasonally and in large numbers.

Precisely which species of native fishes were present in the Waimakariri River prior to human occupation about 1000 years ago is, of course, unknown. However, it is reasonable to

Table A3.1: A checklist of native fish species recorded, or probably found*, in the Waimakariri River system.

While not documented the occurrence of some species, past (or present, marked) is inferred because:

(a) habitats suitable for them existed in the system during Maori and first European settlement; these habitats have since been modified, or have disappeared;

(b) one species—the grayling—was widespread and abundant throughout New Zealand; after European settlement it quickly vanished; and is now believed extinct;

(c) specimen collections in the Waimakariri system have been neither intensive nor comprehensive (systematic sampling would probably identify further species found in other major Canterbury river systems, but not yet recorded from the Waimakariri).

Common Name	Scientific Name	Habit	Features
Longfinned eel	*Anguilla dieffenbachii*	Migratory	Adult breeding at sea. Juveniles return to rivers.
Shortfinned eel	*Anguilla australis*	Migratory	As above. A more coastal, wetland distribution than the longfin.
Lamprey	*Geotria australis*	Migratory	Reproduce in freshwater. Juveniles go to sea after several years.
Common smelt	*Retropinna retropinna*	Migratory	A marine/estuarine fish, though ranging well into freshwater—some freshwater dwelling lake populations.
Stokell's smelt	*Stokellia anisodon*	Migratory	A marine/estuarine fish spawning in lowland freshwater. Juveniles go to sea after hatching.
Inanga	*Galaxias maculatus*	Migratory	Lowland fish—adult matures in freshwater, spawns where tide rise hatches eggs, fry go to sea and return as 'whitebait' (a juvenile stage).
Giant kokopu	*Galaxias argenteus*	Migratory	Adult inhabits quiet waters with good cover. Life history similar to Inanga. Important, large food fish to Maoris.
Koarao	*Galaxias brevipinnis*	Migratory	Adults dwell in fast-water, forested streams. Marine or lake juvenile stage —juveniles 'run' as 'whitebait'.
Common river galaxies	*Galaxias vulgaris*	Freshwater dwelling	Widespread in stony or gravel-bottomed streams.
Alpine galaxias	*Galaxias pausispondylus*	Freshwater dwelling	In mountain streams by Southern Alps.
*Banded kokopu	*Galaxias fasciatus*	Migratory	Swamps, quiet waters with good cover. 'Whitebait' juvenile stage.
*Shortjawed kokopu	*Galaxias postvectis*	Migratory	A rarely-found fish of native forest streams; has a juvenile 'whitebait' stage.
*Longjawed kokopu	*Galaxias prognathus*	Freshwater dwelling	Headwater mountain streams.
Torrentfish	*Cheimarrichthys fosteri*	Migratory	Adults live in fast-water, stony riffles. Young, or eggs, carried to sea.
Canterbury mudfish	*Neochanna burrowsius*	Freshwater dwelling	A fish of swamps, drains and muddy pools; aestivates in mud during drought conditions.
Redfinned bully	*Gobiomorphus huttoni*	Migratory	Fish of rapid-flowing, stony coastal streams. Young go to sea for larval stage.
Bluegilled bully	*Gobiomorphus hubbsi*	Migratory	Lowland fish of stony rapids. Young go to sea, return as juveniles.
Giant bully	*Gobiomorphus gobioides*	Migratory	A large 'bully' found in estuaries, and river mouths.
Common bully	*Gobiomorphus cotidianus*	Migratory	Widespread in quieter rivers and lakes. Young go to sea.
Upland bully	*Gobiomorphus breviceps*	Freshwater dwelling	The commonest South Island 'bully'—widespread in a variety of habitats.
Black flounder	*Rhombosolea retiaria*	Migratory	Principally coastal or estuarine, but often found many kilometres inland in fresh water.
Yellowbelly flounder	*Rhombosolea leporina*	Marine fish	Common in estuaries, and found sometimes, in close by fresh water.
Kahawai	*Arripis trutta*	Marine fish	A shoaling fish which frequently penetrates tidal reaches in large numbers.
Stargazer	*Leptoscopus macropygus*	Marine fish	Common in estuaries.
Yellow-eyed mullet	*Aldrichetta forsteri*	Marine fish	The common 'herring' of coastal and estuarine waters and lower reaches of the rivers.
*Cockabully	*Tripterygion nigripenne*	Marine fish	Common in estuaries.
Red Cod	*Physiculus bacchus*	Marine fish	Enters estuary, seasonally.
New Zealand sole	*Peltorhamphus novae-zeelandiae*	Marine fish	Found in estuaries.
Grayling	*Prototroctes oxyrhynchus*	Migratory	A shoaling fish of coastal rivers and streams—once abundant, now believed extinct.

*Not recorded for the Waimakariri, but, because of known distribution, will probably be listed after more comprehensive sampling.

Table A3.2: Checklist of introduced fishes found in the Waimakariri River system.

Common Name	Scientific Name	Habit	Features
Brown trout	*Salmo trutta*	Migratory or freshwater dwelling	The most common and ubiquitous of the river's salmonids. Wide range of habitats. Some spend extensive periods at sea, others live resident lives.
Rainbow trout	*Salmo gairdnerii*	Freshwater dwelling in NZ	Much less common in rivers. Lakes and river populations. Seems to prefer fast-water habitat, with good cover pools.
Quinnat salmon	*Oncorhynchus tshawytscha*	Migratory	Juveniles go to sea. Return as maturing adults to spawn. Some lake populations.
Mackinaw	*Salvelinus namaycush*	Freshwater dwelling	New Zealand's sole population in Lake Pearson. Uncommon lake char.
Brook trout	*Salvelinus fontinalis*	Freshwater dwelling	Found in many parts of Canterbury, but uncommon. A small and growing char in our rivers. Mostly found in small, cold streams, with upwelling water.
Goldfish	*Carassius auratus*	Freshwater dwelling	Occasionally found in gravel pit ponds.
Rudd	*Scardinius Erythrophalmus*	Freshwater dwelling	A small 'coarse' fish illegally introduced into New Zealand. Declared noxious, but still spreading. Prefers quieter, slower water.

assume the species mix then was much the same as it is today. One species not found today, but which once ran in large shoals is the grayling (*Prototroctes oxyrhynchus*) (Allen, 1949). It was widespread in stony-bottomed rivers throughout New Zealand, but by 1870 it had become noticeably less plentiful, and since 1920 no trace of it has been found anywhere. What caused the extinction of the grayling remains a mystery, although some effect of European settlement seems the most likely explanation (McDowall, 1978).

To say that substantially the same species mix exists now in Waimakariri River, as it did centuries ago, is not the same as saying that the fish exist in the same abundance, or in the same places. Changes to the lower river, and throughout the catchment, begun first by the Maori, and later rapidly and more significantly by the European settlers, have drastically altered the habitats for some of the native fishes.

INTRODUCED SPECIES

The settlers of Canterbury came principally from the British Isles. They found they were surrounded by many fine rivers, lakes and streams, in which the native fishes were strange and different from the ones they had known. Some of the fish were reasonably abundant and of a sufficient size to provide food. But, on the whole, they were not particularly attractive; neither did they offer much in the way of excitement or satisfaction when caught for sport.

As the settlers started to change the flora and fauna, and the landscape into a more familiar Antipodean version of 'Home', it was natural that they make an attempt to change the character of the fishes of the rivers and lakes as well.

How this was accomplished is a story of its own, but for its uniqueness of effort and the success achieved it is one without equal (Nicols, 1882; Thomson, 1922). The fishes they tried, or successfully introduced, were Northern Hemisphere mid-latitude freshwater species, mostly, but not entirely, salmonids.

Several of the 'firsts' in introductions took place in Canterbury—brown trout (1867), eastern brook trout (1877), goldfish (1877), mackinaw or Great Lakes char (1906) are examples.

Brown trout were first released into the Waimakariri system in 1867 (into the Cam River), quinnat salmon in 1877, and rainbow trout sometime after 1885 (Lamb, 1964). The mackinaw was liberated into Lake Pearson where it remains New Zealand's sole wild stock of this species.

The introduced trout and salmon—the so-called 'acclimatised' fish—dominate the present-day use of the river's fisheries resources. To a lesser extent, a few native food-fish species ('whitebait', flounder, mullet, red cod, kahawai) have a popular following of fishermen in the estuarine reach. These uses are primarily recreational, and are enjoyed by men, women and children. Since the Waimakariri River lies close to the major population centre of the South Island, many people from all walks of life find its opportunities for recreational fishing convenient and rewarding.

QUINNAT SALMON

Of all the fishes the introduced quinnat salmon engenders the greatest interest. An anadromous fish (i.e., the young are born in freshwater, descend to the sea as juveniles, and return to the river as mature adults to spawn), their 'run' from the sea to freshwater as large, powerful fish brings many hundreds of people to the Waimakariri River in summer and autumn to try to catch them. These salmon are ranked among the finest food fishes in the world, and provide a high level of excitement and challenge to the sport angler.

Although transplanted far from its natural home in the rivers rimming the North Pacific Ocean, the quinnat has adapted to the nature and moods of the Waimakariri River because it is essentially of a similar character to its native rivers. The freshes and floods bringing discoloured, or dirty water, stimulate the sea-run salmon to migrate up the river towards their spawning grounds. They do not feed, so the food resources present, or their lack, are of no concern. In its native range the quinnat, and four related species of anadromous salmons, are prey for other animals (bears, other mammals, bald eagles, several large fish-eating birds, etc.). Possibly as a survival mechanism it is a wary, nervous fish during river passage, moving quickly to cover if some aerial movement disturbs it. The upstream migration to the spawning grounds may occupy days, weeks, or even months. During that time the turbid water—or if the water is clear, the holes, deep water in runs, undercut banks and overhanging vegetation—provide cover and shelter.

Salmon on first entering the river from the sea are at their most vulnerable to capture by angling. As they progress further up the river, they become more difficult to catch, particularly while in active passage. The deeper holes and shelter places where they lie up for short periods, offer the angler further opportunities to catch them. Both dirty water and clear water frustrate the fisherman: on the one hand the fish cannot even see the lure being offered; on the other the fish is wary, and inclined to ignore the lure, or seek cover. Fortunately, and for reasons not satisfactorily explained, some of the non-feeding, migrating salmon do take the lure offered, and are caught, thus providing a sporting rod-and-line fishery over the river between the mouth and the spawning grounds.

The female quinnat salmon is a gravel nest builder. The process of nest (redd) construction and spawning has been described by Briggs (1953), Hobbs (1937) and other workers. Redds are most often constructed in a stable gravel substrate, although recently disturbed but immobile substrate may also be used. The choice of a nest site seems governed by the stability of the substrate, the size of the gravels, and the movement of water through the substrate, with the latter factor probably the most critical. The fertilised eggs, buried deep in the gravels of the redd, depend on the water infiltrating past them for survival and development. The dissolved oxygen content of this water maintains life while water temperature governs the rate of development and the time of hatch. Once hatched, the larval salmon (called alevins) develop further within the redd before moving up through the interstices of the gravel to the surface of the streambed, where they begin an active, feeding, stream life prior to downstream migration.

The most favourable conditions, for either salmon or trout spawning and juvenile production, exist in stable, gravel-bedded streams that are not subject to scouring floods: the poorest conditions occur in unstable streams where alluvium is moved or deposited by floods.

The effects of highly-variable flow in a spawning stream range from redds being destroyed by scouring of the substrate, to the flow ceasing, leaving the redd (and its eggs) stranded high and dry. The most common cause of poor survival, or non-survival, of eggs or larval fish within the redd is sediment carried by the discharge. The main effect is the reduction or complete cessation of the water flow through the gravel substrate, causing death by suffocation. A second effect is that of sediments settling out as a layer on the surface of the gravel. This can cause oxygen depletion in the sub-surface flow (since there is no exchange of dissolved oxygen through the gravel interface), but also when the tiny alevins attempt to reach the gravel surface they are unable to penetrate the crust of sediment, and die.

Juvenile quinnat salmon begin to leave the streams as fry (30–40 mm length), and the peak of their outmigration is in the spring. Spring is the time when the mainstem river—the course the fish must follow to reach the sea—often experiences floods resulting from the equinoctial westerly gales bringing rain to the Main Divide. Many of the migrating fry, possibly the majority, do not survive the river's floods, with high velocity flows, turbid with suspended sediments and moving bedload. Some do survive these conditions, using the low-velocity micro-habitats behind large stones and along the channel margins to shelter in, and maintain position. Survival in the river is seemingly higher for juvenile quinnat that migrate later as larger fingerlings and yearlings, according to research in progress on the neighbouring Rakaia River (Hopkins, 1981).

The ability to survive the river's floods, and to then feed and grow in freshwater is crucial if the year's brood of young salmon is to successfully contribute mature adult fish in succeeding years to maintain the salmon population. But young anadromous salmonids also have to develop the ability to survive the transition from a freshwater environment to life in the saline environment of the sea. It involves physiological changes, generally described as 'smoltification', with most of the changes occurring in freshwater. (Smoltification is a process which varies among different species of anadromous salmonids, but with quinnat salmon seems related to an optimum juvenile size and age. The process is not fully understood, but is subject to much current research.) When the process is complete the 'smolt' is functionally adapted to survive the transition from fresh to salt water (Wedemeyer, *et al.*, 1980).

It is also likely that the juvenile quinnat migrating downstream will encounter periods of low discharge in the river, with lesser water velocities, and clear conditions. While the problems created by floods are absent, these small fish become natural prey for other fish, and several species of birds (gulls, terns, herons, etc.). The availability of protective cover is then important for survival.

3. The Impacts of Settlement

The coastal area between the Ashley and Waimakariri Rivers was long the home of Maori peoples: firstly the Waitaha, then the Ngati-Mamoe, and lastly the Ngai-Tahu (Hawkins, 1957). It was a place of swamps, forest, quiet streams, and shallow coastal lagoons set behind sand dunes. It was a place rich in aquatic life, eels (particularly the tasty 'silver-belly' shortfin), giant and banded kokopu, 'whitebait' and inanga, all close to hand in the swamp and forest drainage. In the lagoons, flanking river and estuaries, there were more eels, smelts, flounder, mullet, grayling and other fishes. There were shellfish to be had from the sea beaches and tidal flats. It was a place wisely chosen for its sources of food.

Kaiapohia Pa, the main settlement, was constructed of trees cut by stone tools from the adjacent forest. Flaxes and raupo were gathered for their many essential uses, firewood collected and scrubland cleared to prepare small patches of ground for kumara. The Maoris, in their travels, used fire to clear vegetation for hunting. The human need to use and thus change the environment had begun its inexorable progress.

European settlement of the lower Waimakariri district brought great changes. The forests went, felled for timber or burnt through carelessness, and with them went the forest-floor

litter and the shade for the secretive kokopu of the bush streams. The extensive swamps were drained by channelling their water into tidy ditches devoid of cover from the vanished raupo, toetoe and flaxes. With the swamps went the habitat for the shortfinned eel and the inanga. The foothill rivers (the Eyre and the Cust) feeding the swamps were channelled and diverted away. The former swamps and forest land were dried out, cleared and tilled, and the fertile soils made into productive farms, largely free from the threat of inundating floods.

Of the several alluvial islands in the aggrading delta reach of the Waimakariri River, Kaiapoi Island was the largest. When the district was first settled in the mid-1800's one branch of the river went around the south of the islands (the South Branch, which was the immediate flood threat to nearby Christchurch), and a second to the north around Kaiapoi Island where it joined with the Eyre, Cust and Cam Rivers draining the inland swamps (refer to Figures 2, 9–11 in text). The North Branch and the South Branch recombined below the present town of Kaiapoi to form a single river flowing to the sea.

Kaiapoi Island was one of the first areas settled in North Canterbury. Originally swampy, the soils of the island when drained were amongst the most fertile to be found anywhere. But the farmers soon found that the island lay directly in the line of flood spillage from the Waimakariri River. After several floods in the 1850's and early 1860's, with parts of the island submerged, crops destroyed, and river shingle spreading to cover productive farmland, the farmers had had enough. By hand they began to dig a new channel to divert the floods away and below Kaiapoi Island. Kaiapoi township, further downstream on the North Branch, also suffered severe damage from these floods, which caused great hardship to the new settlers.

Over a period of years the Waimakariri River tended to take the new course (the New North Branch) and the Old North Branch gradually became sealed off by alluvial deposits. Today, properly stopbanked and protected from incursion by the Waimakariri River, it forms the upper reach of the Kaiapoi River and is a small, spring-fed, stony-bottomed stream wandering quietly through farmlands. The banks and bed are stable, and willows, scrub and grasses edge its course. It is now a much more productive habitat for fish than the rampaging old North Branch which preceded it.

The new North Branch existed for many years as a companion to the South Branch. Since the new branch had cut across the top of Kaiapoi Island, the portion of the island remaining to the south became Coutts Island. Below Coutts Island the new North Branch joined the South Branch shortly above the Empire Bridge (Old Highway Bridge) where the north road linking Christchurch and Kaiapoi crossed the Waimakariri River. The whole river then flowed in the South Branch channel to meet the Kaiapoi River just below the township.

In time, extensive works along the south bank from Halkett downstream, intended to protect Christchurch from the Waimakariri's floods, sealed off the South Branch, and the North Branch became the sole channel for the river. The present South Branch rises in springs and seepage downstream from the Crossbank above Harewood, and flows through farmland and the edge of an industrial area on the outskirts of the city. It is a pleasant, quiet stream, extremely productive of trout, and intensively used for several kinds of recreation.

The mouth of the Waimakariri River is a bar mouth discharging over constantly-shifting sandbanks deposited by the action of the sea. Historically, the position of the mouth moved north or south over a distance of several kilometres and seemed to locate more frequently at a point towards the southern end of the present Brooklands Lagoon. During periods of low river flow it was not uncommon for the sand bars to build up, blocking off the mouth. Then the water would rise behind the coastal sandspit until it was able to force open a new mouth. When a blocked mouth coincided with the advent of a flood, some time could elapse until the mouth opened, and the pent up floodwaters, already delayed in reaching the sea by constricted and lengthy river channels, aggravated the flooding problems about Coutts Island. With the Waimakariri River Trust's scheme, control works eventually fixed the river mouth in its present position at Kairaki. A narrowed, free-flowing tidal mouth was created through which the floodwaters, directed by a shortened river channel past Stewart's Gully,

were readily discharged. Perhaps more importantly for the fish, it then allowed the estuary to operate as a true tidal environment, uninterrupted by mouth blockage, and the ponding of the river's fresh waters.

4 The Effect of Flood Control Works on Fish

A major effect of the confinement of the river in its lower reaches to a single semi-braided channel, and the blocking of natural flood overflow channels on the fan upstream, was to increase the volume of flood water per unit width of channel. With this increase in available stream power during floods relative to its "uncontrolled" regime (refer in text to Section 5.1 and Figures 25, 26 and 27), coarse sediments (mainly gravels) were more readily transported downstream into former silty meandering channels flowing across the lower floodplain.

When considering the impacts of floods on fish and their habitats, both the volume of the flood and its sediment load are of major importance. The volume of a flood does not cause problems for a fish, but the velocity of the flow, if it exceeds the ability of the fish to swim against it, or hold position, may cause displacement downstream. However, the velocity through the river's cross-section is not constant, and in deeper pools and runs near to the bottom, close to the bank, behind large rocks and stones, there are reduced velocities in which the fish can shelter until the flood subsides.

An active, healthy fish can tolerate high concentrations of suspended sediments for a time without harm. In flood the Waimakariri River transports a large part of its alluvium as fine sediments in suspension, a circumstance assisted by the turbulence of the water. These floods have a short duration, usually peaking within a few hours, and rarely remain at a high level for more than 2 to 3 days.

Prolonged turbidity, at concentrations of between 80 and 400 mg/1 suspended solids, will result in degradation of fish habitat (EIFAC, 1965). Instances have been recorded of fish surviving concentrations well in excess of 100,000 mg/1 for short periods. Sediments deposited by floods have the most direct effect on fish by destroying the benthic fauna which provides their food, and by smothering eggs or larval fish.

The greater and persisting problem of natural aggradation in the reach where the bed gradient markedly decreases (downstream from the Crossbank), has been tackled by straightening the course of the river and directing the flow into a single channel in which the discharge can develop sufficient energy to move the alluvium downstream on a flattened slope. Except in great floods, the Waimakariri River is not known to carry its gravels to the river mouth. The bed of the estuary is largely composed of fine sands and silts. Since the time Speight (1927) recorded the position of the gravel tongue as about a kilometre below the old Empire Bridge, and with the channelisation of this part of the river that has taken place, gravel deposits now extend to about 2.5 km from the sea. Apparently, because of the large-scale extraction of shingle and sand by road construction and concrete-making firms upstream, these deposits have not appreciably extended since 1960 (Griffiths, 1979). Further encroachment of coarse gravels covering the fine, productive sediments of the estuary would have a profound effect on its aquatic animal populations.

Little study has been made of the fishes of the major braided alluvial rivers of the Canterbury Plains. For example, the Waimakariri as a system has been only occasionally and fragmentarily sampled to determine the species composition and distribution of native fishes. Particular fish, such as *Galaxias prognathus* (longjawed kokopu) found in the upper Rakaia catchment, have not been identified from the Waimakariri River, possibly for no other reason than that they have not been looked for. Even less study has been made of the ecology of fishes in such systems.

Recently, research has been started on anadromous quinnat salmon—probably the most important of the introduced fishes to utilise these river environments. Considerable progress has been made in understanding the effects that highly variable river discharge and unstable alluvial habitats have on the survival and growth of juvenile quinnat migrating to sea.

Despite their apparent lack of cover and meagre food supplies, the large braided rivers are significant producers of brown trout. The ecology of brown trout in a major Canterbury river has not yet been studied.

The knowledge that has been gained on fish resources of these braided rivers has mostly been from the Rakaia River, a river which has not been extensively modified by river control works for flood protection. Although the lower Waimakariri River has been significantly modified, the effects of the river control work there on fish resources has not been examined, and can only be inferred.

Clearly, the development of the region from the time of first European settlement has destroyed or changed habitats once favourable to some native fishes. The drainage of the swamps would have decreased the number and range of the shortfinned eel. Similarly, the marshy spawning margins used by inanga have been drastically reduced and the resulting runs of 'whitebait' made smaller. Forested streams and quiet backwaters in swampy drainages which harboured kokopu and inanga have gone.

The introduction of large, predacious trout utilising the smaller native fishes (smelt, bullies, galaxiids) for food, and competing with them for a share of the invertebrate animals and the available living space, presumably has had a profound effect on the ecology of the river. Not the least of man's endeavours has been the successful establishment of many kinds of exotic plants—particularly streamside vegetation and aquatic weeds—which have influenced the food supply and cover available for fish.

Arising from the flood protection structures and the river control works the most likely effect has been to increase the amount of cover for fish. Additional cover has been formed in the deep holes that are sometimes scoured at the head of the large spur groynes. These groynes tend to create quiet backwaters where small fish can shelter and feed. Where the streamside willow and popular trees fall into the water when the supporting bank is eroded away, their branches, and the debris that collects where they are submerged, add considerably to the available cover. Trees, felled and wired back to retard bank erosion, often form behind them sizeable areas of quietly-moving water, liberally provided with both overhead and submerged cover. Insects of terrestrial and aquatic origin tend to collect or drift into such places, and remain available to the fish for a longer time than does food drifting down in the swifter open channels. Similarly, the extensive lengths of large, rough rip-rap rock placed to control bank erosion create changes to water velocity which improve holding conditions for fish. The rip-rap also has many submerged gaps and crevices which make excellent cover for eels and other fishes of cryptic or secretive habit. Where the control works have reduced multiple braids to fewer large channels or a single main channel, then water depth is increased, particularly in times of low flow, and more cover is available for fish. in this situation it is easier, for example, for upstream migrating adult sea-run quinnat to make passage through the mainstem. In large channels the 'holding' holes for these fish tend to be deeper; where deep holes are formed by the groyne heads and runs of increased depth occur along the foot of rip-rap banking, salmon can find places to pause and lie up for a while before continuing on to the spawning grounds. It is probable that brown trout find the bankside runs and pools, overhung with willows and containing good shelter in the form of debris piles in the water, a more favourable habitat than the open shallower channels of the riverbed. In the case of the Waimakariri River, the lower river (reach 3, downstream from Crossbank) now appears to have a more intensely braided, multiple channel system than its "pre-control" channel system.

The planting of many hectares of willows and poplars along the river banks and the stabilisation of the alluvial margins with grasses and shrubby bushes will have significantly added to the food supply for fish. Terrestrial insects are a large contributor to the river's invertebrate drift, which is a major part of the food supply for stream-living fishes.

Although the sealing off of the old South and North Branches and the channelisation of foothills rivers, such as the Cust, which historically fed the swamps between Kaiapoi and Rangiora, have formed useful, stable, gravel-bedded streams, the flood protection and river

Figure 1: The Waimakariri River bed gravels deposited in a recent flood, overlying older river deposits. (C. Hardy, MAF)

Figure 2: Riparian "Cover" along the Waimakariri River provided by rip-rap and willow bank protection works. (C. Hardy, MAF)

control works which have modified much of the present lower reaches of the mainstem Waimakariri have not stabilised the gravels. Indeed, the intent of much of this work is to encourage the movement of alluvium downstream to reduce the bed aggradation occurring in the reach of decreased bed slope. After a sizeable flood in July 1983, there was visible evidence of massive bedload movement in the stretch above the Motorway Bridge. Extensive,

freshly deposited gravels overlaid earlier deposits of silts, and along the river margins and backwaters thick layers of fine sediments covered older, coarser, alluvium. While these works do what is intended of them in protecting the adjacent land from inundating floods, they only temporarily and locally provide some benefit for the fishes of the river.

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Appendix 4

The Water Quality and Benthic Biology of the Waimakariri River and its Tributaries—A Summary

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Water Quality

Data on the water quality of the Waimakariri River system are mainly from the lowland section of the river below the gorge. Bowden and Ayrey (1983) summarise typical levels of a range of determinands for the river at Halkett Groyne. For the lowland tributaries significant studies include Ayrey (1982) who assessed the effects of the meatworks organic waste discharge on the water quality of the South Branch, Fowles (1971) who tabulates data for the Kaiapoi/Cam Rivers, and Winterbourn *et al.* (1976), Toshach (1976) and Winterbourn and Stark (1978) who tabulate data for the Kaiapoi/Ohoka Rivers. All the data on the Kaiapoi and Cam Rivers relate to industrial pollution. Table A4.1 lists known reports on the water quality of the Waimakariri system. A considerable amount of further data is held by the author and the North Canterbury Catchment Board. The NCCB data are being reviewed for a Waimakariri Resource Assessment study (Ayrey pers. comm.).

Table A4.1: Summary of studies carried out, or containing data, on the Waimakariri River System

	Waimakariri River	South Branch	Styx River	Avon River	North Branch	Cam River	Kaiapoi River	Northbrook Drain
Ayrey (1982)	waterqual.	waterqual.						
Bowden and Ayrey (1983)	waterqual.							
Bennington (1971, 1977)							inverts.	
Biggs (1985)						waterqual. periphyton		
Burnet (1968)		fish						
Burnet (1969)		fish inverts.						
Dalmer (1971)				inverts.				
Fowles (1969)								
Fowles (1971)						waterqual. inverts.	waterqual. inverts.	
Fowles (1972)		inverts.						
Hamilton (1972)	waterqual.	waterqual.					waterqual.	
Hirsch (1958)	inverts.	inverts.			inverts.	inverts.	inverts.	inverts.
Marshall (1973)				inverts.				
McCammon (1972)			inverts.					
MOW (1956)	waterqual.	waterqual.					waterqual.	
MOW (1961)	waterqual.	waterqual.					waterqual.	
MOW (1968)	waterqual.	waterqual.					waterqual.	
Robb (1980)			inverts. plants	inverts. plants				
Toshach (1976, 1977)							waterqual. inverts.	
Winterbourn *et al.* (1976)	waterqual. inverts.					waterqual. inverts.	waterqual. inverts.	waterqual. inverts.
Winterbourn Stark (1978)							waterqual. inverts.	

The Waimakariri River above the confluence of the South Branch receives no waste discharges and drains poorly developed pastoral and alpine catchments. The waters are therefore expected to be of a high quality, and the limited available data would appear to support this (Table A4.2).

A set of samples obtained in May 1983 (author's data) indicates that the main river carries lower levels of total solutes than the lower reaches of some of the spring-fed tributaries (Table A4.3). However high levels of suspended solids occur in the main river, causing considerable grey discoloration which markedly contrasts with the clearer spring-fed tributaries. The lowland spring-fed tributaries all appear to have high quality waters near their sources. Industrial organic discharges to the Cam River and the South Branch have resulted in degradation of water quality to these systems (Table A4.4), and the Avon River appears to

Table A4.2: Baseline water quality data for the Waimakariri River at Halkett Groyne (from Bowden and Ayrey, 1983).

Determinant	Level
pH	7.9
Dissolved Oxygen (%sat^{-n})	96.0
Bicarbonate (g.m^{-3})	29.0
Chloride (g.m^{-3})	1.0
Sulphate (g.m^{-3})	5.0
Sodium (g.m^{-3})	2.2
Potassium (g.m^{-3})	0.5
Calcium (g.m^{-3})	9.0
Magnesium (g.m^{-3})	1.0
Nitrate-N (mg.m^{-3})	100.0
Ammonia-N (mg.m^{-3})	5.0

be polluted with street wash during fresh events. The meatworks discharge to the South Branch is substantial enough to also pollute the Waimakariri River below the confluence with the South Branch (Table A4.5). This results in sewage fungus growth and malodorous conditions in the vicinity of the Highway Bridge during summer low flows. Water quality in the Kaiapoi River has previously been degraded by a fellmongery discharge, but the factory no longer exists and the waters are now expected to have improved in quality.

Table A4.3: Comparison of various water quality determinands between the Waimakariri River and spring-fed tributaries.

Determinand	Waimakariri	Avon	Styx	South Branch
Temperature (°C)	11.0	11.0	11.5	12.0
Dissolved Oxygen (g.m^{-3})	10.8	7.5	9.9	9.8
pH	7.7	7.2	7.5	7.3
Conductivity (mS.m^{-1})	5.1	14.18	7.24	10.53
Turbidity (F.T.U.)	65.0	1.6	0.34	0.48
Total Suspended Solids (g.m^{-3})	313.0	3.7	15.8	0.89

Table A4.4: The effects of organic waste discharges on the water quality of the South Branch and Cam River (Ayrey 1982, Biggs 1983).

	Sth Branch Above Discharge	Sth Branch Below Discharge	Cam River Above Discharge	Cam River Below Discharge
	(mean levels)			
pH	7.1	7.1	7.3	7.3
Dissolved Oxygen (g.m^{-3})	8.9	7.9	10.5	8.3
B.O.D.$_5$ (g.m^{-3})	2.0	31.0	0.5	8.2
Ammonia (mg.m^{-3})	90	950.0	9.5	10.5
Total Kjeldahl-N (mg.m^{-3})	-	-	193.0	395.0
Sulphide (g.m^{-3})	<0.05	0.39	-	-

Benthic Fauna and Flora

There are few data on the biological communities in the main Waimakariri River. Most work has been carried out on the lowland tributaries, and varies considerably in detail and objectives. Significant studies include: Burnet (1968, 1969), Fowles (1972) and Hirsch (1958) who have considered fish, invertebrates and pollution in the South Branch; McCammon (1972) and Robb (1980) who have surveyed invertebrates and aquatic macrophytes in the

Table A4.5: The effects of organic pollution from the South Branch on the water quality of the Waimakariri River (from Ayrey 1982).

	Above SH 1	500 m below South Branch	2 km below South Branch
	(mean levels)		
pH	7.6	7.4	7.3
Dissolved Oxygen ($g.m^{-3}$)	10.7	9.5	9.7
B.O.D.$_5$ ($g.m^{-3}$)	1.4	4.4	5.2
Ammonia ($mg.m^{-3}$)	5.0	90.0	84.0
Sulphide ($g.m^{-3}$)	-	0.05	0.3
Faecal Coliforms (MPN/100 ml)	286	5.7×10^5	3.6×10^4

Styx River; Fowles (1971) and Hirsch (1958) who studied invertebrates and pollution in the Cam River; and Fowles (1971), Toshach (1976), Winterbourn *et al.* (1976) and Winterbourn and Stark (1978) who studied invertebrates and pollution in the Kaiapoi River (Table A4.1) Detailed records on periphyton communities in the catchment have been collected by the author but are currently unpublished.

The lowland tributaries generally carry a rich and diverse benthic flora and fauna (Burnet 1969, McCammon 1972, Robb 1980). The stable flow patterns and channels, and lack of extensive pollution will have assisted these communities to develop. The aquatic macrophytes *Myriophyllum* sp., Characeae, *Potamogeton cheesemanii*, and *Elodea canadensis* are found extensively throughout the lowland tributaries, providing habitat for invertebrate populations and assisting to stabilise bed sediments (Winterbourn *et al.* 1976, Robb 1980).

Filamentous algal communities occur on coarse stable sediments. Taxa that may dominate include *Cladophora* sp., *Ulothrix zonata, Stigeoclonium* spp., *Vaucheria* sp., *Spirogyra* spp. and Microspora sp. (Biggs unpublished data, Winterbourn *et al*, 1976, Robb 1980). Extensive beds of green algae have been noted in the Cust Main Drain (a tributary of the Kaiapoi River) and the South Branch. Sewage fungus also grows extensively in the South Branch, this being in the lower reach below the meatworks discharge, and in the main river below the South Branch tributary. Sewage fungus also grows in Cam Creek, below the peel factory discharge (Biggs 1985).

Invertebrate communities in the lowland tributaries vary depending on the habitat (Table A4.6). Hard sediments, such as gravel and stones, appear to be dominated by larvae of insect taxa with *Deleatidium* sp., *Olinga feredayi* and *Pycnocentria evecta* being prominent. The snail, *Potamopyrgus*, may also be abundant, particularly where large mats of periphyton develop.

In areas of soft sediment (sand, silt and organic deposition) the invertebrate community tends to be dominated by worms (Lumbricidae), Chironomidae, and the molluscs *Gyraulis corinna* and *Sphaerium novaezelandiae* (Table A4.6). In general, the fauna of these habitats appear considerably less diverse than those of the stable heterogeneous gravel-stone habitats.

The aquatic macrophyte habitat contains a range of invertebrate taxa that has elements common to both hard and soft substrates (Table A4.6). *Potamopyrgus antipodarum*, Chironomidae and Oligochaeta are particularly abundant taxa. The crustacea *Paracalliope fluviatilus* is also often recorded.

Quantitative data (Winterbourn *et al.* 1976) indicate that invertebrate standing crop in the lowland spring-fed systems is generally high. The discharge to the South Branch has further enhanced this, in its downstream reaches. However, only few taxa (Oligochaeta) appear able to survive the harsh water quality conditions and take advantage of the added organic matter below the discharge. These taxa appear to have proliferated (Winterbourn *et al.* 1976).

Table A4.6: Compendium of invertebrate taxa commonly found dominating the community for various substrate types in the Waimakariri River system (compiled from Bennington 1977, Burnet 1969, Fowles 1971, Marshall 1973, Robb 1980, Toshach 1977, Winterbourn *et al.* 1976, Winterbourn and Stark 1978).

	Substrate		
	Hard	**Soft**	**Macrophytes**
Annelida—Oligochaeta	(+)*	+	+
Diptera—Chironomidae	+*	+	+
Mollusca			
Gyraulis corinna		+	
Physa sp.			+
Physastra sp.	+		+
Pisidium sp.		+	
Potamopyrgus antipodarium	+*	(+)	+
Sphaerium novaezelandiae		+	
Crustacea			
Paracalliope fluviatilus		(+)	+
Insecta			
Coloburiscus humeralis	+		
Deleatidium sp.	+		
Helicopsyche sp.	+		
Hydrobiosis parumbripennis	+		(+)
Hydropsyche sp.	+		
Olinga feredayi	+		+
Oxyethira albiceps	+	(+)	+
Pycnocentria evecta	+		+
Pycnocentrodes aureola	+		
Zephlebia sp.	+		

( ) = less frequently common
* = particularly when periphyton is abundant

The few data available on the main Waimakariri River indicate that it is a particularly inhospitable environment, as expected, probably due to the unstable bed sediments. *Deleatidium* sp. constituted much of the fauna in the few data quoted, with Elmidae (water beetle) also being present in significant numbers. Below the confluence with the polluted South Branch, the sediment is often covered with algal slime and sewage fungus, and fauna appears to have a very low diversity. Oligochaeta may be the predominant taxa (Winterbourn *et al.* 1976).

Discussion

Information on the water quality and benthic biology of the lowland Waimakariri River system is widely distributed at present.

Severe pollution in the lowland tributaries has resulted in a number of studies to determine its effects, and these have added considerably to the knowledge of these areas.

In the North and South Branches the pollution previously altered the nature of the substrate by depositing fine particulate organic matter on the stream beds, and reducing oxygen levels. The accumulation of organic matter has created conditions more suitable for burrowing organisms (e.g., Oligochaeta) than for the larger surface dwelling taxa, resulting in low invertebrate diversities in some areas. Discharges to the Waimakariri River system are now confined to the South Branch and Cam River. This is likely to have resulted in improved water quality for some tributaries, particularly the Kaiapoi River.

Comparative studies have indicated that in unpolluted reaches of the lowland tributaries the invertebrate communities may fluctuate in relative composition, but overall, they are reasonably stable and rich. This is probably a reflection of the stream's stable physical character and continuity of similar landuse practices in the area. Flood control works are likely to have assisted this stability by preventing periodic flushing of the minor tributaries or

preventing the main channel from changing course and causing a loss of these lowland habitats. The stable lower tributaries are now a considerable asset to the Christchurch metropolitan area in that they provide recreational and aesthetic uses.

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6.	A guideline for the construction of access tracks and firebreaks. ($2.20)	1980
7.	A guideline to skifield development. ($2.20)	1980
8.	A wetlands guideline. ($5.50)	1982
9.	A water and soil guideline for mining. ($11)	1983
10.	A water and soil guideline for pipeline easements. ($4.40)	1985

Prices include G.S.T. and postage.