WILLOWS AND RIVER CHANNEL MORPHO-DYNAMICS

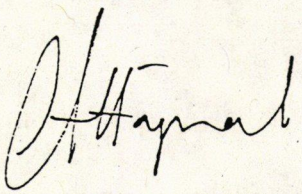
Analysis of the role of willows (Salix fragilis) in channel adjustment along the Mararoa River, Southland, New Zealand.

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This thesis has not been submitted to any other university or institution.

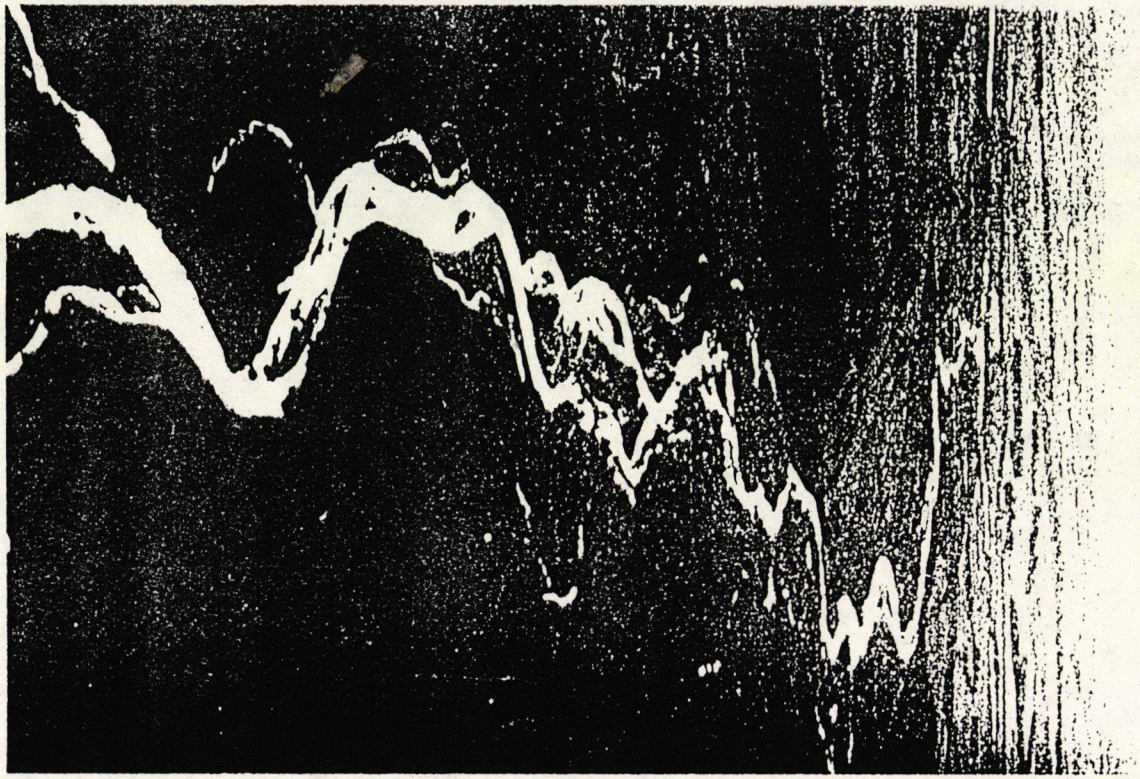


November, 1993.

ABSTRACT

The Mararoa River is a dynamic gravel-based river in western Southland, South Island, New Zealand. Analysis of aerial photographs and field data indicates that willows have played an important role in channel adjustments along the lower course of the Mararoa River. Aerial photographs from 1948 predate the introduction of willows onto the Mararoa River, showing a river reach which has low sinuosity, multiple channels and high instability. Aerial photographs from 1957, 1970, 1979, 1987 and 1991 show a gradual change in planform to a reach which has one or two moderately stable channels of higher sinuosity. The change in planform can be summarised as a change in river type from a braided to a wandering gravel-bed style.

Field analysis of bar surfaces in the reach between The Key Bridge and Fern Hill show that willows are an important control in the distribution of geomorphic units on bars. Willows were shown to influence localised fluvial processes such as bank accretion, flow resistance, slope buttressing, bar development, and formation of log jams and debris constrictions. On a larger scale, willows have contributed to the formation of willows swamps, channel abandonment, channel degradation and frequent localised flooding of the floodplain. Willow/ river interactions vary spatially and temporally according to discharge levels and sediment availability. These variables, combined with human modifications in the catchment, control willow and river channel morpho-dynamics.



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CHAPTER ONE - INTRODUCTION

1.1 SIGNIFICANCE AND SCOPE OF THE RESEARCH

1.1.1 Statement of aims

The aim of this study is outline the role of crack willows (Salix fragilis) in influencing channel adjustment on the lower course of the Mararoa River, Southland, New Zealand. The relationship between channel changes on the Mararoa River since 1948 and the introduction of willows was examined through two main techniques: aerial photograph interpretation of channel changes, and field analysis of willow and river interactions.

The purpose of aerial photograph interpretation was to determine whether channel change had occurred since the introduction of willows, and to assess the extent of change. Analysis was made of six aerial photograph sets from 1948, 1957, 1970, 1979, 1987 and 1991. The 1948 run predates the introduction of willows into the river environment, and subsequent runs were useful in demonstrating changes in river morphology.

Field analysis consists of an examination of geomorphic units and the distribution of willows on bar surfaces, and tree ring dating to determine the establishment dates of willows on these units. Willow and river interactions were addressed in four central questions. These are:

1. WHERE do willows and rivers interact?
2. HOW do willows and rivers interact?
2. WHEN have these interactions occurred?
3. WHY do these differing styles of interaction take place?

The first question addresses whether there are any patterns in the location of willows in relation to geomorphic units on bar surfaces. The second question aims to outline the range of willow behaviour that occurs. The third question analyses the time period in which river/willow interactions have occurred, and relates these interactions to the flood history. The final question examines the controls on willow and river morpho-dynamics.

1.1.2 Relevance and scope of study

The use of vegetation in river management, both its addition or removal, is common practice in New Zealand and throughout the world. Yet there is minimal understanding of the role of vegetation in the river environment, and little thought is given to the impact introduced vegetation has on river systems, particularly in the long-term. Improvement in our understanding of vegetative interaction with rivers is vital in the effective management of rivers. Furthermore, assessing the role of vegetation in river channels will improve our interpretation of past and present fluvial processes and landforms.

As noted by Van Zon (1990), the influence of vegetation on water supplies is treated extensively in the literature, including the determination of water balances, measurements of evapotranspiration and precipitation. However, the effects of vegetation on river forms and processes is poorly documented. Hickin (1984) acknowledges that the role of riparian vegetation is considerably understated in fluvial geomorphology because it is not easily quantifiable and physically or statistically manipulable. This has lead to the virtual exclusion of vegetation-related fluvial processes from geomorphic literature.

This study attempts to provide a counter-balance to the dearth of studies on vegetative interaction with rivers. By taking a multi-disciplinary approach, the study endeavours to explain localised form-process associations on the Mararoa River in the context of the river as a whole. The interrelationships between changes in the vegetation regime and changes in channel morphology are outlined, using the methods of aerial photograph interpretation and field analysis. The study, consequently, has relevance to the fields of fluvial geomorphology, ecology and resource management.

One of the main limitations of the study is the lack of baseline data on the river. There were no base-level surveys ever carried out along the river and there is no baseline data available on channel bed slope, channel depth, or flow velocity, so possible changes in these variables caused by the encroachment of willows cannot be determined. The extent of channel instability is difficult to evaluate from aerial photographs, however, channel width, sinuosity and number of channels can be reliably determined from the photographs. This allows some conclusions to be made on channel planform changes.

There is virtually no information on river morphology before 1948 apart from a few historical photos. Rainfall data in the area was recorded from 1952 onwards. Hydrologic data is poor, with records only as far back as 1976. There is no information on the rate of bank erosion or how this has changed since the introduction of willows.

Six relevant aerial photograph runs were available between 1948 and 1991. As the Mararoa River is a dynamic river photographic sets from 1948, 1957, 1970, 1979, 1987 and 1991 might be insufficient to convey the range of

channel adjustments occurring in this period. Furthermore, the dates for the 1948 and 1979 sets are unknown and these two runs have incomplete coverage of the reach being analysed.

Considerable changes in land use have occurred since European settlement of the area in the 1850s. Clearance of forests, burning of tussockland, drainage of swamps, introduction of animals, and establishment of agricultural activities have had indirect consequences on river morphology. These factors are difficult to quantify, resulting in difficulties in isolating the role of vegetation in channel adjustment. Further research on the interaction between vegetation and river systems, especially long-term monitoring, is required before the role of willows in channel adjustments along the Mararoa River can be adequately quantified.

1.2 FRAMEWORK OF THE THESIS

This report follows the basic framework of a scientific report with chapters on previous literature, regional setting, methodology, results, discussion, conclusions, and recommendations.

Chapter Two reviews the literature on the nature of rivers and the interaction between rivers and vegetation. Geomorphic characteristics of braided and wandering gravel bed planforms are described in the first section. Variables controlling river behaviour are considered, and are placed in a spatial and temporal framework. River metamorphosis is discussed.

The second section in Chapter Two deals with vegetative interaction with rivers, particularly the impact of willows on river systems. The roles of vegetation on fluvial processes and forms are reviewed, including flow

resistance, bank drainage, soil reinforcement, slope buttressing and soil arching, surcharging, bank accretion, bar sedimentation, log jams and debris constrictions. The physiological characteristics of willows (Salix sp.), including their propagation techniques, are considered.

Chapter Three is a comprehensive review of the history of the Mararoa River and its regional setting. Physical aspects of climate, landscape evolution and geology, influence of glaciation, soils, gemorphology, vegetation and hydrology are discussed. Human modification of the catchment, including land use change and introduction of willows, is outlined.

Chapter Four outlines the methods used in this study. These include aerial photograph interpretation, field analysis, tree ring dating of crack willows (Salix fragilis), and interviews. Criteria for reach and site selection are given. Photogrammetric analysis was performed on six sets of photographs from 1948 to 1991 to determine channel adjustment in this time period. Site analysis was based on the location of willows in relation to geomorphic units on bar surfaces. Tree ring dating was carried out on 77 willows to determine dates of establishment on fluvial landforms. Interviews were also carried out to gain a better picture of the history of the catchment. Persons interviewed included farmers, people of Te Anau, and people involved in management of the river.

Chapter Five presents the results of the photogrammetric analysis. Figures show channel adjustments from 1948 to 1957, 1957 to 1970, 1970 to 1979, 1979 to 1987, 1987 to 1991, and 1948 to 1991. Sinuosity and number of channels was determined for each photo set. Cross-sections were drawn at each site for every photo run to determine changes in channel position and width. Channel changes were related to the flood history, using hydrology

and rainfall data.

Chapter Six presents the data from the field analysis of specific sites. The distribution of geomorphic units and willows is illustrated in planform maps. Establishment dates of willows on fluvial landforms was recorded. This chapter also addresses the location of willow and river interactions, the range of river/willow interactions and the timing of interactions.

Chapter Seven synthesises the results of Chapter Five and Chapter Six. Channels changes are summarised and the spatial and temporal scales of channel change are considered. The controls on willow and river morpho-dynamics are assessed.

Chapter Eight makes conclusions on the role of willows in channel adjustment along the Mararoa River, relating the changes to channel morphology to the introduction and spread of willows.

Chapter Nine outlines the management options available on the Mararoa River. These include a 'do nothing' approach, maintenance of the willows, complete removal of willows, and restoration to the original floodplain conditions. Recommendations are made and the need for further research is emphasised.

CHAPTER TWO - LITERATURE REVIEW

2.1 NATURE OF RIVERS

2.1.1 Introduction

A vast range of river morphologies exist in nature, with the character and configuration of rivers varying markedly in different environmental settings. A widely recognised river classification system is by river planform, comprising the number of channels, channel sinuosity and channel stability (see Figure 2.1 - 1).

2.1.2 Geomorphic characteristics of braided and wandering gravel-bed river styles

Braided rivers are characterised by two or more rapidly shifting channels of low sinuosity. High width/depth ratios and high gradient slopes are attributes of braided rivers. In most examples, a single dominant channel can be distinguished within the overall braided pattern, although several principal channels can also develop. Mechanisms of braiding are discussed by Rundle (1985a and 1985b). Several distinct topographic levels may be recognised, ranging from the area of the deepest and most active channels to elevated, abandoned areas, commonly covered by vegetation (Miall, 1977:2-9).

The deposits of braided rivers are coarser than those of other river types and are dominated by sand or gravel. The braided river style is generally associated with higher energy situations, in which flow is either unable to carry its entire sediment load (insufficient flow capacity), or parts of the sediment load are too coarse (insufficient flow competence).

TABLE 2.1 - 1
Classification of river types

TYPE	NO. OF CHANNNELS	SINUOSITY	STABILITY	Erosive behaviour	Depositional behaviour
Meandering	1	>1.3	stable	channel incision meander widening	point-bar formation
Braiding	2	<1.3	unstable	channel widening	channel aggradation, mid-channel bar formation
Straight	1	<1.5	stable	minor channel widening and incision	side-channel bar formation
Anastomosing	2	>2.0	very stable	slow meander widening	slow bank accretion
Wandering	1	~1.3	moderately stable	channel widening and incision	channel aggradation, mid-channel bar and point-bar formation

SOURCE - Miall (1977:4) and Brierley (1991)

Wandering gravel bed rivers, as noted by Church (1983) and Deslodges and Church (1987), are characterised by fewer channels and active bar platform areas than in braided reaches. Generally there is one dominant channel which is irregularly sinuous in outline and splits around vegetated bars. Seasonal side channels, or subordinate anabranches of the river, are common (Deslodges and Church, 1987).

The wandering style is distinguished by an irregular pattern of channel stability. Stable reaches consist of gravel-based, lateral and point bars, and unstable reaches have sporadically active mobile gravels and sands (Brierley, 1992). Channels wander primarily across valley rather than down valley. Lateral accretion is the dominant mode of deposition (Deslodges and Church, 1987).

2.1.3 Controls on river behaviour

The planform of a river is a response to certain combinations of environmental variables which vary spatially and temporally. Rivers have pronounced down-valley transitions, reflecting localised controls on river character (Brierley, 1992). As stated by Kellerhals et.al. (1976:815), classification of a river "should proceed by individual 'homogenous' reaches, i.e., channel reaches (of variable length) within which hydrological, geological, and adjacent watershed surface conditions remain sufficiently uniform so that a sufficiently uniform river morphology results".

Temporal variations are placed into a three-scale framework by Hickin (1983). A geologic time-frame entails study of river development at the catchment scale over thousands to millions of years. Regional tectonic history and glaciation are environmental controls at this scale. These

factors condition landscape form and the nature of material available to a river. Geomorphic scale has a time-scale ranging from individual events that last a matter of seconds, to lagged adjustments occurring over thousands of years. Such controls include lateral constriction placed on a river, variations in sediment input to a river, or flow regulation. Understanding of these controls on form/process associations can give insight into river evolution and response to altered environmental conditions. Engineering time is determined by the "design-flood regime", typically the 100 year flood. Such effects are brought about by changes to the hydrologic and/or sedimentation regime of a river (Brierley, 1992).

Interrelationships in fluvial systems, including independent basin controls, independent channel controls and dependent channel variables, are shown in Figure 2.1 - 1. According to Knighton (1987:87), the dominant controls on channel form are discharge (amount and variability) and sediment load (amount and grain size).

Geology and climate are important external controls. Geology acts as a constraint on channel adjustment through its influence on bed and bank material composition, most notably in bedrock channels (Knighton, 1984:88). Geology of a basin also affects the type and rate of sediment supplied to the channel. River discharge broadly correlates with mean annual precipitation. Rainfall intensity and seasonality are important parameters in influencing the availability of water (Knighton, 1984:17-18).

Vegetation also plays several important roles, including a stabilising influence on bed and bank materials, and a constraint on channel adjustment. Riparian influences are shown in Figure 2.1 - 2. Vegetation exerts control on fluvial processes and forms through flow resistance, bank

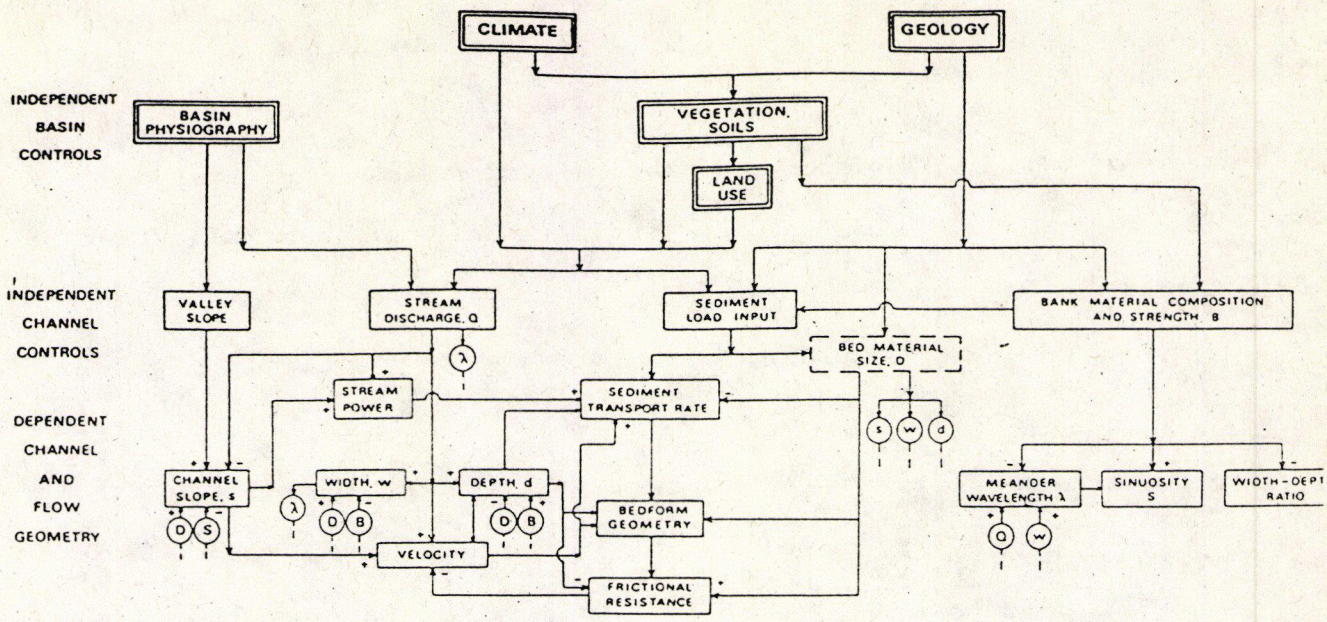


FIGURE 2.1 - 1
Interrelationships in the fluvial system

SOURCE - Knighton (1984:2)

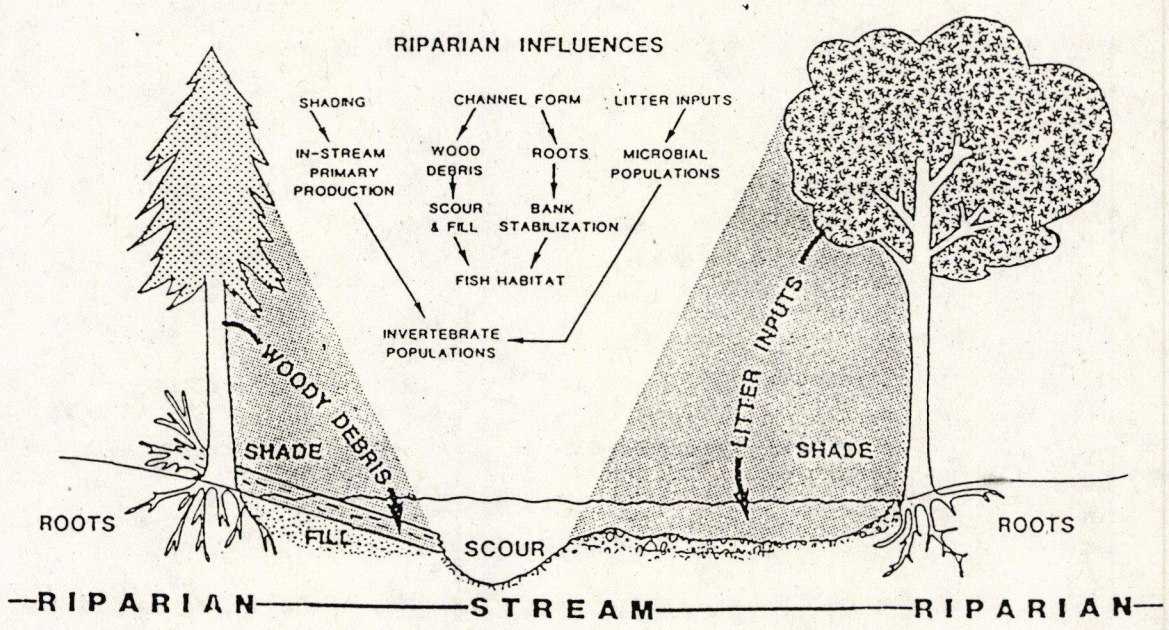


FIGURE 2.1 - 2
Riparian influences on rivers

SOURCE - Cummins (1986:48)

drainage, soil reinforcement, slope buttressing and soil arching, surcharging, bank accretion, bar sedimentation, and log jams and other debris constrictions (Hickin, 1984). These aspects are discussed further in the section on vegetative interaction with rivers.

Human impacts on river environments have been extensively discussed in geomorphological literature, including Patrick et.al. (1982), Hickin (1983), Knighton (1984), Warner (1987), and many others. Human impacts include river regulation, vegetation clearance, agriculture, sand/gravel extraction and urbanisation on river systems. It is now accepted that humans have altered fluvial forms and processes to such an extent that they can be considered one of the most influential geomorphic agents. Almost all river systems reflect some degree of human modification (Patrick et.al, 1982).

2.1.4 Channel metamorphosis

As noted by Brierley (1992), planform type is sensitive to changes in environmental setting. Any change in these controls may bring about adjustment in channel style, referred to as channel metamorphosis by Schumm (1969). Schumm cites the main causes of channel metamorphosis as associated with changes in discharge and types of sediment load.

River channel changes can be influenced by changes in vegetation distribution, as found by Gregory and Gurnell (1988). Nevins (1969) found that the planting of willows along the Turanganni River in New Zealand instigated a change in river channel pattern from a braided river to a single thread channel. A similar phenomena has occurred on the Mararoa River, Southland, where change from a braided river to wandering gravel bed river style has occurred since 1948.

2.2 VEGETATION AND RIVERS

2.2.1 Vegetative interaction with rivers

Vegetative effects on rivers are complex. Not only is vegetation itself an influence upon river channels and river channel processes, but in addition fluvial processes exercise an influence upon vegetation type and distribution (Gregory and Gurnell, 1988). Unfortunately, the difficulty in quantifying the role of vegetation in fluvial systems has lead to the virtual exclusion of vegetation-related fluvial processes from the research experience (Hickin, 1984).

Studies by Smith (1976), Hickin (1984), Hickin and Nanson (1984), Osterkamp and Hupp (1984), Gregory and Gurnell (1988), Malanson and Butler (1990), Thorne (1990) have found that vegetation exerts a significant control over fluvial processes. Vegetation was found to influence the processes of water flow and the transport of sediment. Vegetation affects the overall channel morphology and the detailed features of the river channel (Gregory and Gurnell, 1988).

Most studies have concentrated on the influence of vegetation on bank stability. As described by Greenway (1987) and Thorne (1990), vegetation can significantly affect both flow erosion and bank stability. Bank vegetation increases the effective roughness height of the boundary and increasing flow resistance. This has the effect of reducing the forces of drag and lift acting on the bank surface (Thorne, 1990).

Vegetation not only protects the soil surface directly but roots bind the soil, adding tensile strength. A study in Canada by Smith (1976) found that bank sediment with 16-18% root volume had 20000 times more resistance to erosion than banks without roots. Root elasticity distributes stresses

through the soil, so avoiding local stress build-ups and progressive failures. However, for roots to be effective in stabilising banks they must penetrate through the potential zones of failure to the low water plane (National Water and Soil Conservation Authority, 1984; Thorne, 1990).

Vegetated banks are drier and much better drained than unvegetated banks. Evapotranspiration improves slope stability by lowering pore water pressures at the potential failure surface, with a consequent increase in soil shear strength (National Water and Soil Conservation Authority, 1984). Bank drainage reduces the bulk unit weight of the soil, enhancing the stability of the bank with respect to mass failure (Greenway, 1987; Thorne, 1990).

Trees can also act as gravity buttresses and/or cantilever piles with soil arches between them. A buttress retains a slope and loads the toe of a slope against shear failure. Arching occurs when soil is prevented from sliding between or around piles that are firmly anchored in an underlying layer (Thorne, 1990).

Vegetation also plays a central role in promoting sediment deposition on advancing banks through increasing local flow resistance. The deposited sediment forms a basal accumulation that further stabilises the bank by protecting intact bank material from flow attack, and loading the toe against mass failure (Thorne, 1990). Bank accretion has an important role in floodplain development, including meander loop extension and point-bar development (Hupp and Simon, 1991). Similarly, vegetation that has been stranded on mid-channel bars can also enhance the rate of bar development by trapping further quantities of debris or sediment (Thorne, 1990).

Mosley (1981), Hickin (1984), Gregory and Gurnell (1988), and Nakamura and Swanson (1993) found one of the most significant ways in which channel morphology is influenced by vegetation is through the development of log jams and debris dams. Logs and large debris can accumulate and filter out other vegetative debris being carried by the river, until the jam is substantial enough to deny the river access to the floodplain (Hickin, 1984). Studies along Canadian rivers by Hickin (1984) show that channel abandonment and flow diversion have been associated with log jams. Debris dams can also significantly alter the slope of a river channel (Mosley, 1981; Gregory and Gurnell, 1988).

Gregory and Gurnell (1988) also report that differences in channel form can be related to different types of vegetation. Maddock (1972), for example, argues that tree-lined channels are deeper and narrower and therefore possess a lower width-depth ratio than channels which have grassed banks. Such differences can be attributed to the fact that tree roots penetrate deeper, increasing the shear strength of the banks compared with grass covered banks (Gregory and Gurnell, 1988:18). Thorne (1990) states that factors such as type, density and spacing of vegetation, its age and health, are also important considerations in assessing the role of vegetation in fluvial systems.

2.2.2 Willows (Salix sp.)

Willow is the common name given to members of the genus Salix within the family Salicaceae. There are about 300 species and varieties in the genus. Most originate from the temperate regions of the Northern Hemisphere, although some are native to South America and South Africa. None are native to New Zealand or Australia. Due to the ability of willows to adapt to diversified climatic conditions, willows have spread over vast geographical

areas and now have an almost world-wide distribution (Warren-Wren, 1972; Van Kraayenoord and Hathaway, 1986:139; Frankenberg and Mitchell, 1993:1).

Willows generally have long narrow leaves with small leaf buds. Most willows are deciduous and this results in significant leaf-fall in the autumn and bare trees in the winter. This can increase the potential of bank failure in winter due to destabilising pore water pressures (National Water and Soil Conservation Authority, 1984).

Willow species are dioecious with male and female flowers on separate plants. Sexual reproduction culminating in the production of seeds will, therefore, only occur if both sexes are present. In New Zealand most willow species are represented by one sex only, depending on the selection of the parent tree from which the cuttings were taken. In most cases the willow population can be traced to a single introduction of willows which have spread asexually through broken branches (Van Kraayenoord and Hathaway, 1986: 140; Frankenberg and Mitchell, 1993:1).

The main morphological form of willow used in river management is the tree willow. These are relatively large trees that can grow to a height of 15-30 metres, depending on the species (Frankenberg and Mitchell, 1993:2). The crack willow (Salix fragilis) is New Zealand's most common and widespread tree willow, and is the only species planted on the banks of the Mararoa River in Southland. A native of Europe and Asia, it was introduced to New Zealand about 1840 and spread rapidly throughout the country during the early days of settlement. All crack willows in New Zealand are male, so its only form of propagation is through broken branches and twigs, or cuttings (Van Kraayenoord and Hathaway, 1986).

The crack willow develops into a large tree upto 20 metres high with wide-spreading branches and a broad crown. Branches grow at angles from 60 to 90 degrees to the parent branch. The twigs are dark brown, hairless and glossy, and are very brittle, snapping easily at the base with a cracking sound (hence the name 'crack' willow). This accentuated brittleness of its limbs in winter is a serious disadvantage in its use for river protection work. The leaves are long, lance shaped, glossy green above and bluish green below, with a coarsely toothed margin (Grant, 1948:20; Green et.al., 1989; Van Kraayenoord and Hathaway, 1986:141).

2.2.3 Impact of willows on river environments

The training of braided gravel-bed rivers into single-thread channels through the use of willows is a long and continuing activity in New Zealand (Nevins, 1969; Griffins, 1989). Willows are frequently used in bank stabilisation works as they are cheap and flexible, absorbing the erosive energy of large flows without expensive bank protection works (Green et.al., 1989; Gordon et.al., 1992).

Willows reduce flow velocity by increasing channel roughness and encourage sediment accumulation, thereby stabilising banks and reducing erosion (Gordon et.al., 1992). The dense root system of willows stabilises bank material very effectively. Roots also grow into the water, trapping sediment so that the bank is built out below the water line (Gordon et.al., 1992; Frankenberg and Mitchell, 1993:5).

Other attributes of willows include their ease of establishment and their high tolerance to low fertility soils and unfavourable site conditions (Hathaway, 1976; Gordon et.al., 1992; Frankenberg and Mitchell, 1993). Willows are a quick-growing species which are able to respond to erosion

events rapidly and recolonise eroded areas of bank. Native species are usually slow to mature and are likely to be attacked and washed out before they are established (Thorne, 1990).

Willows growing on the banks of streams and hanging over into the water can be important to fish populations, especially brown trout. The provision of shade and the lowering of water temperatures, especially in summer, is essential for the survival of trout (Latta, 1974; Mosley, 1983; Tierney, 1986). Willows provide nutrient regulation, filtering of sediments, and nesting areas for bird (Platts and Rhine, 1985; Cummins, 1986; Risser and Harris, 1989; Gordon et.al., 1992).

However, problems resulting from willow infestation were reported in New Zealand as early as 1948 by the Soil Conservation and Rivers Control Council of New Zealand (Grant and Fenton, 1948). A recent example of problems encountered with the use of willows in river management comes from the Tauweru River in the North Island of New Zealand. An article in Rural News (July 5 1993) states that the uncontrolled growth of willows along the river has lead to the frequent flooding of valuable farmland, with farmers facing thousands of dollars in damage from wrecked fences, ruined pastures and the cost of grazing out starving stock until the paddocks recover. Farmers claimed that the floods were becoming more frequent as uncontrolled willow growth causes a steady silting up of the river bed, changing the river from a former gravel-bed river to a "muddy, sluggish, almost stagnant water body". When attempts to establish a flood control scheme failed, due to lack of consensus between farmers and catchment authorities, a group of farmers hired a helicopter to spray willows along a 15.6 km section of the river. These farmers are now being prosecuted by Wellington Regional Council.

This situation highlights a commonly observed problem with the use of willows in river management: if willow growth is uncontrolled they can increase local flooding hazards due to insufficient channel capacity. Channel capacity is reduced as a result of encroachment of willows within streams and the trapping of sediment and debris (Graf, 1980; Hathaway, 1976; Rankin, 1980; Hathaway, 1986). Other reported impacts of willows on river systems include narrowing and deepening of the channels. Channel degradation can increase the bank height so that the rooting depth of the willows is exceeded. This allows undercutting of the bank as the willow roots no longer penetrate to the toe of the bank. The surcharge effect of the weight of the overhanging tree can cause mass failure of the bank, and toppled trees cause flow obstruction (Rankin, 1980; Thorne, 1990).

Willows readily invade natural riparian plant communities. Once established, willows cast dense shade and invade new territory with their roots, quickly dominating the surrounding vegetation. The lack of understorey under a continuous stand of willows has serious implications for the fauna using the river margin. Species diversity is diminished both by the loss of the understorey and the different habitat provided by the willow (Graf, 1980; Gordon et.al., 1992).

2.3 SUMMARY

Willows are commonly used in river management because of their stabilising influence on bed and bank materials. However, the uncontrolled growth of willows places a constraint on channel adjustment and can modify channel morphology. This has occurred on the Mararoa River, where changes in reach planform from a braided to a wandering gravel-bed style can be directly attributed to the introduction of willows.

CHAPTER THREE - REGIONAL SETTING

3.1 INTRODUCTION

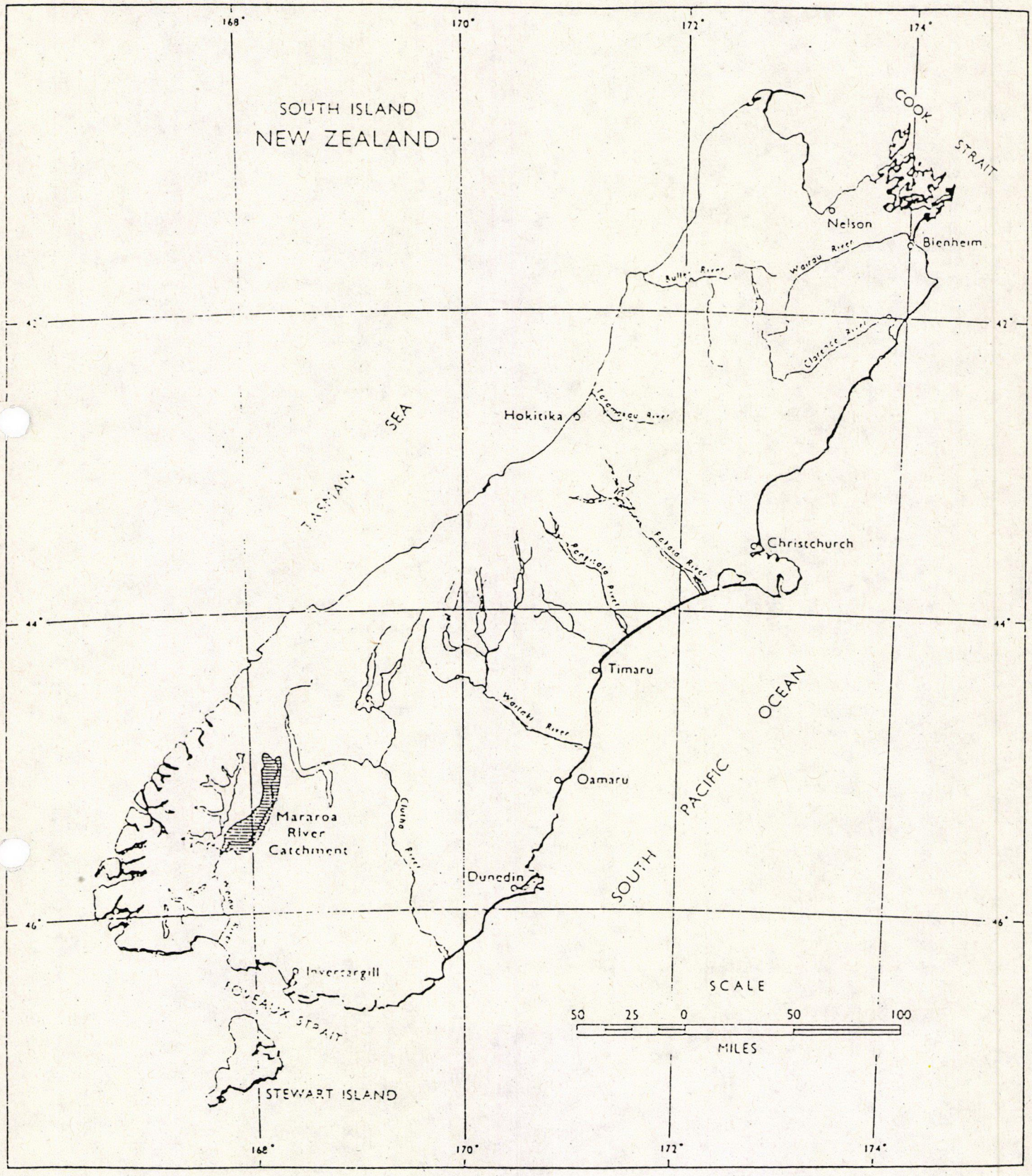
The Mararoa River is a dynamic gravel-based river in Western Southland, New Zealand (Figure 3.1-1 and 3.1-2). Catchment area is 1219 km . The river flows in a south-westerly direction through steep, formerly glaciated terrain to its confluence with the Waiau River. The main axis of the catchment extends some 77 kilometres and its maximum width is about 29 kilometres. The only large tributary of the Mararoa River is the Whitestone River.

3.2 CLIMATE

The bioclimatic character of Southland is termed "Southern Cool Temperate" with warm summers and cool winters. The rainfall gradient rises steeply with elevation, with an annual rainfall in the upper catchment of the Mararoa River in excess of 1 550 mm, decreasing to 1 200mm per annum in the lower catchment (Dunbar et.al., 1966; Mills, 1989; Williams, 1990; Williamson et.al., 1990; Department of Conservation, 1992).

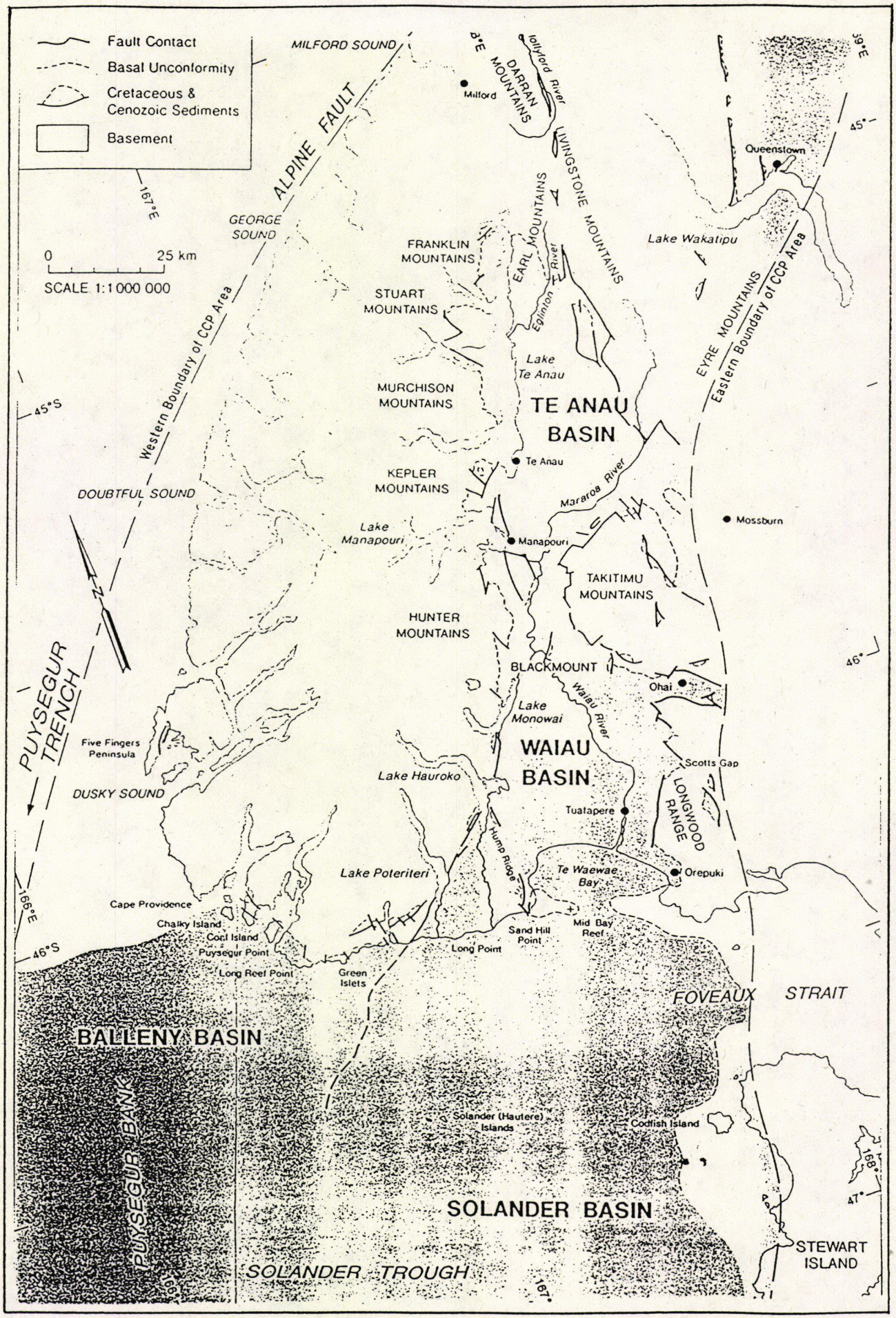
In the study area, rainfall data was available from 1952 to 1991. The recording station is at the Plains Station, 500m away from Key Bridge on the left bank of the Mararoa River (New Zealand Meteorological Service Site No.157581). Annual and seasonal averages are presented in Tables 3.2 - 1 and 3.2 - 3. Average annual rainfall for this period is 1050 mm. Rainfall is highly variable from year to year and is not controlled by a flood- or drought-dominated regime. Longer-term rainfall data from Milford, recorded from 1930 to 1991 at Site No. F47691, shows no patterns or longer-term trends in rainfall (see Table 3.2 - 2).

FIGURE 3.1 - 1
Location map of region



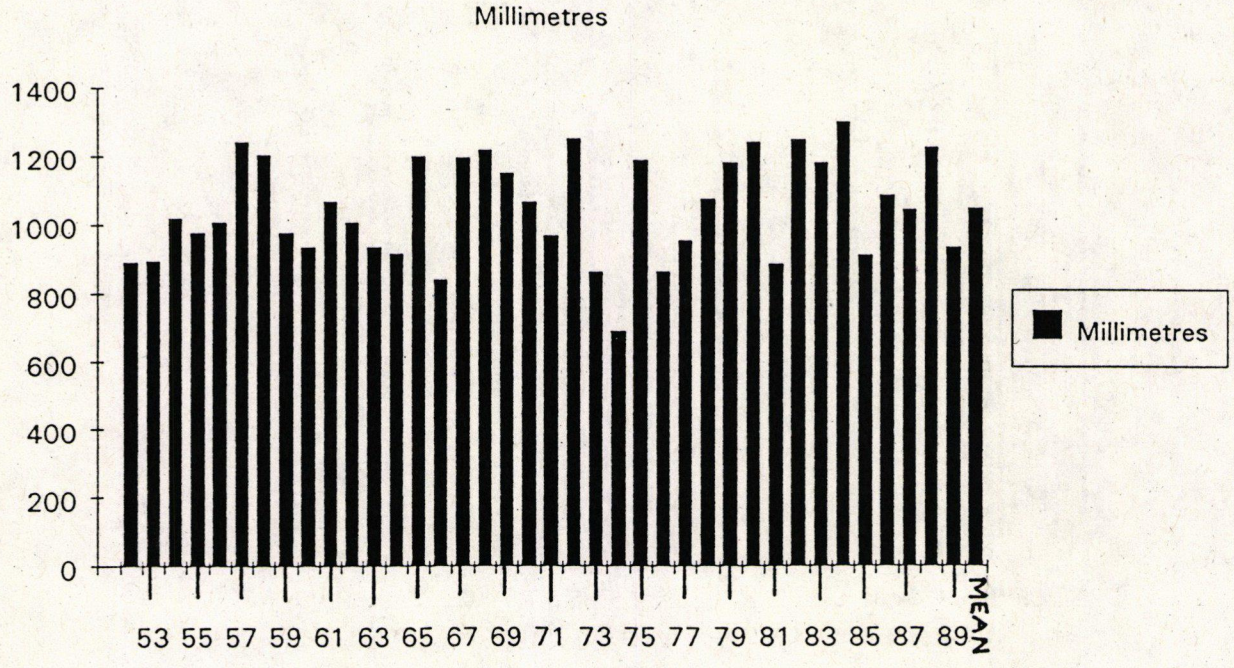
SOURCE - Dunbar, Prickett and Howard (1966:6)

FIGURE 3.1 - 2
Western Southland and Fiordland

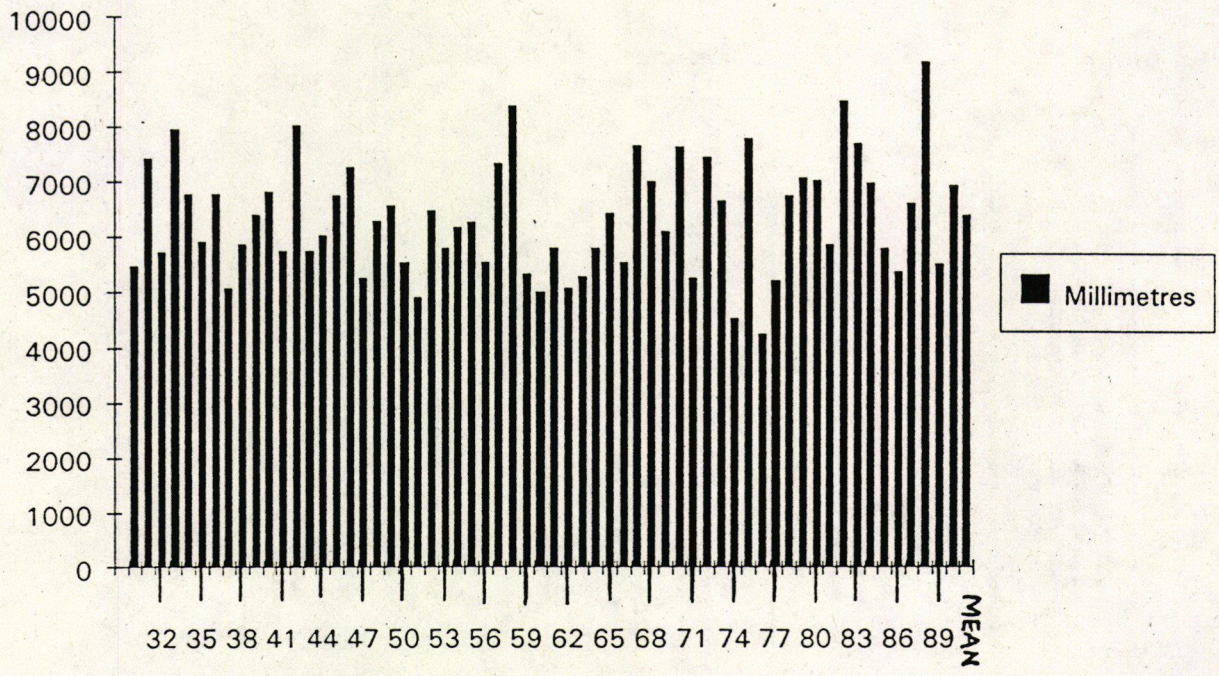


SOURCE - Turnball, Uruski and others (1993)

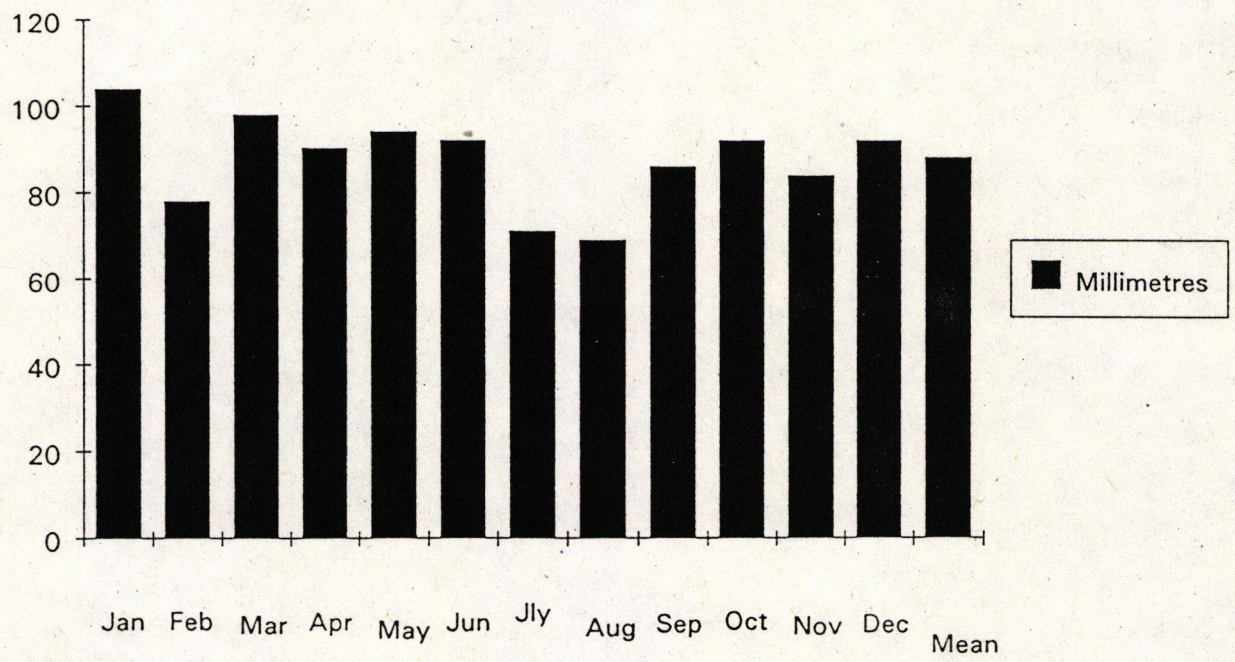
Graph 3.2-1
Annual Rainfall at The Plains, 1952 - 1989



Graph 3.2-2
Annual Rainfall at Milford Sound, 1930-1990



Graph 3.2-3
Monthly rainfall means at The Plains, 1952-1989



Rainfall is evenly distributed throughout the year. Wettest months are January, March, May, June, October and December, and driest are the winter months of July and August.

Mean air temperatures in January are 12.5 - 14.9 C and 4 C in July. Frosts are common and severe in winter. Snowfall is also common in winter, particularly in altitudes above 600 m. Winter temperatures are cold enough for patches of very thin anchor ice to form on streams (Dunbar et.al., 1966; Mills, 1989; Williams, 1990; Williamson et.al., 1990).

High winds are also an important climatic feature, being predominantly from the west and north-west. During spring, frost lifted or cultivated soils can be actively eroded by these winds. Seasonal development of needle ice commonly results in the detachment of the surface soil layer from the main soil body. Strong winds, aided by raindrop impact, have repeatedly removed this layer until a lag gravel is all that remains of the original soil (Dunbar et.al., 1966; Mills, 1989; Williams, 1990; Williamson et.al., 1990).

3.3 LANDSCAPE EVOLUTION AND GEOLOGY

The Western Southland region is bounded by the Alpine Fault to the west of Fiordland, and the Lake Wakatipu region, the Longwood and Takitimu ranges, and Stewart Island to the east. The region lies immediately east of the Pacific-Australian plate boundary. There is an oblique subduction zone in the south, the Puysegur Trench, and changes to a strike-slip fault, the Alpine Fault, west of Fiordland. The tectonic and sedimentary history of the region reflects changing movements on this plate boundary from the Early Miocene (28 m.y.a.) (Turnball et.al., 1993:5).

FIGURE 3.3 1

Geology of the Mararoa Catchment



Macatch

Roads

Mararoa River

Rivers & Streams

Bodies of Water

Sandstone WI

Mudstone

Conglomerate

Argillite

Greywacke

Ancient Volcanics, etc.

Ultramafics

Alluvium

Loess

metres

0 3000 6000

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Basement rocks in Western Southland form Permian to Mesozoic terranes, and range from plutonic and high-grade metamorphic gneisses in Fiordland and Stewart Island, to plutonic, volcanic, volcaniclastic and ophiolite sequences in the Takitimu, Longwood and Livingstone ranges. Schist and semi-schists form a major terrane in the northeast of the region. These terranes are bounded by major high-angle fault systems that were reactivated in the Cenozoic, and represent a phase of terrane accretion on the margin of Gondwanaland (Landis, 1973; McKellar, 1973; Turnball et.al., 1993:5). Geology of the Mararoa catchment is shown in Figure 3.3 - 1.

The present-day Western Southland sedimentary basins are partly covered by Pleistocene till and outwash gravel, or by marine terrace gravels adjacent to the southern coastline. Fluvial and lacustrine depositional environments reflect accumulation in generally north-easterly trending fault-controlled basins, formed during Cretaceous rifting of New Zealand from Antarctica. Seismic activity on the Alpine Fault and Puysegur Trench has been prevalent in recent times. Minor Plio-Pleistocene volcanic activity, associated with subduction on the Puysegur Trench beneath the Balleny and Solander basins, is now quiescent (Turnball et.al., 1993:5).

3.4 GLACIAL HISTORY

A succession of ice advances and retreats in the Pleistocene modified the landscape. Four periods of glacial advance are recognised from the deposits and physiography, and minor recessions took place during two of these periods (McKellar, 1973). During the colder glacial periods ice sheets extended across the Te Anau-Manapouri basin, and extensive fan surfaces developed that merged into the overlapping deposits of glacial outwash gravels. The source of the ice was in the Greenstone River catchment. The

Greenstone Glacier divided near the Mararoa saddle, one stream flowing east to join the Wakatipu Glacier, while the other advanced over the divide into the Mararoa valley and flowed south to the Thomson Mountains (Dunbar et.al., 1966:13).

The result of glaciations has been to modify valley form, producing the characteristic U-shaped valleys with steep slopes, and overdeepening valley floors to produce basins which are occupied by lakes on the retreat of ice. Terminal moraines, each of which represents the maximum extent of ice advances in the last glaciation, exist in several places, and, together with alluvial barriers and post-glacial fans, have created poor drainage and swampy conditions in many parts (Dunbar et.al., 1966:13-15; O'Loughlin and Pearce, 1982:69; Suggate, 1982).

Interglacials and interstadials resulted in dissection of glacial deposits and the lowering of stream base levels (McKellar, 1973). A period of intense erosion was initiated as the glaciers withdrew 10-15 000 years ago and continued sometime into the post-glacial. Many large landslides and extensive scree deposits have modified the steep slopes, and streams have attempted to adjust their courses to modified valleys. Meltwater floods reworked the glacial deposits, and with further fluvial action gave rise to a more dissected and terraced landscape (O'Loughlin and Pearce, 1982:69; Pillans et.al., 1982; Department of Conservation, 1992, p.7-8; Williams, 1990, p.2).

3.5 SOILS OF THE TE ANAU BASIN

Soils of the Mararoa catchment are shown in Figure 3.5-1. Alluvium on the river flats of the major river valleys is normally mixed, having derived from diverse sources. The soil type in the lower catchment of the Mararoa River is mainly Tuatapere soils, which are free draining silt loams to sandy loams. They are mainly shallow and stony with a high to medium natural nutrient status that is suitable for intensive grazing, cropping and production forestry.

In flat, low lying and swampy areas Manapouri soils have formed typically a black peaty silt loam with low fertility and low erosion risk. They occur in the drainage depressions amongst the Wairaki soils north of the Mararoa River, and also the narrow swampy valleys of the streams draining the Dunton soil areas (Dunbar et,al., 1966; O'Byrne, 1986; Mills, 1989).

Terraces along the Mararoa River consist mainly of gravels and fines derived from granite, diorite and gneiss. Drummond shallow soils are silty loams occurring on the flat intermediate terraces along both sides of the lower Mararoa River (Dunbar et.al., 1966:27; O'Byrne, 1986).

3.6 GEOMORPHOLOGY AND VEGETATION OF THE MARAROA CATCHMENT

The Mararoa catchment is divided geographically by Dunbar et.al. (1966) into two separate regions:

1. The high country area above South Mavora Lake.
2. The arable area at the lower end of the catchment extending from South Mavora Lake to the Waiau River.

The upper catchment is characterised by narrow valleys and steeply sloping mountains ranges rising to between 1800 and 2200 metres above sea level,

FIGURE 3.5 - 1

Soils of the Mararoa Catchment



Township
Macatch
Mararoa River
River & Streams
State Highway
Roads
Bare Rock
Recent Soil
Gley Recent Soils
Gley Soils
Organic Soils
YB Loams
Brown Granular Loams to YB Earths I
Brown Granular Loams & Clays
Alpine Steepland Soils
Redzina & Related Soils
Upland Podzolised YB Earths & Podzols
Lowland Podzolised YB Earth & Podzols
Upland & High Country YB Earths
Lowland YB Earths
YG to YB Earth
Bodies of Water

metres
0 3000 6000

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while in the lower catchment there are extensive areas of rolling and flat land, with the Takitimu Mountains in the south rising to over 1500 metres above sea level. The general elevation of the lower river flats and surrounding rolling country is about 300 and 450 metres above sea level. About 64% of the catchment area is steep to very steep, 16% rolling to moderately steep and 20% flat to gently sloping (Dunbar et.al., 1966:10-16). Vegetation of the catchment is illustrated in Figure 3.6-1.

The lower catchment was divided by Brierley (1993) into seven reaches, as shown in Figure 3.6-2. The first reach, South Mavora Outlet reach, extends from the outlet of the lake to the break in the forest cover, coincident with the widening of the valley flats. This reach is characterised by a very stable, incised single channel with irregular sinuosity. The reach is laterally confined, and there are no bars evident. Vegetation is undisturbed beech forest.

Hikuraki reach extends from the downstream limit of beech forest to a less constrained channel section adjacent to Little Hill. The reach is characterised by a relatively stable, low sinuosity channel. A bedrock gorge confines the channel mid-reach. Bars, banks and alluvial flats are covered in tussock, with occasional matagouri, flax and cutty grasses.

Haycocks reach extends from Little Hill down to the right bank bedrock constriction between Burwood and The Key. In this reach the valley widens considerably from upstream reaches, and the channel becomes multi-channelled with extensive alluvial flats. The channels have low sinuosity and are wider and shallower than upstream, and there is a greater abundance of active bar surfaces. The channels are laterally unstable, with poorly defined banks, erosion on outside of bends, and greater inundation of

FIGURE 3.6 - 1

Vegetation of the Mararoa Catchment



Roads

Mararoa River

Rivers & Streams

Catchment Boundary

Bodies of Water

Broom

Gorse

Scrub

Forest

Tussock

Pasture

Swamp Vegetation

metres

0 3000 6000

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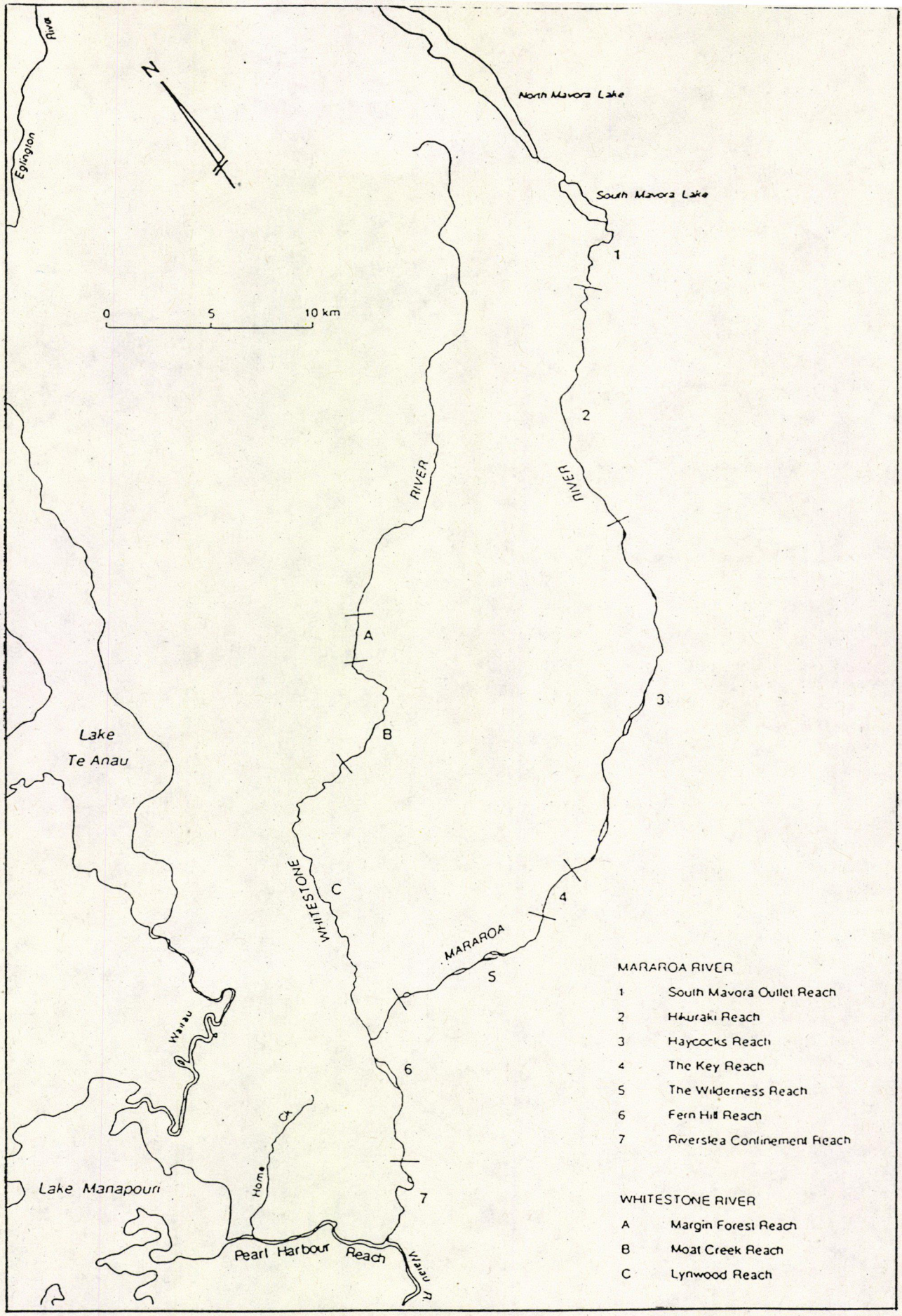


FIGURE 3.6 - 2
Reaches of the Mararoa River

SOURCE - Brierley (1993)

channel-marginal flats by secondary channels. Vegetation is mainly shrubby grasses and weeds with the occasional tussock and matagouri.

The Key Reach extends from Burwood Station to The Key Bridge. This reach is less multi-channelled and has a lower sinuosity than upstream. There are fewer active gravel surfaces and bars are generally restricted to bank-attached features in a well-defined channelised zone. The Mararoa River abuts against bedrock on its right bank for most of this reach. The channelised zone is densely vegetated by gorse and broom with the occasional matagouri. Willow becomes dominant at the lower end of the reach. There is little evidence of active channel expansion into the vegetated flats.

The Wilderness reach, where the field analysis was undertaken, extends from The Key Bridge to Fern Hill. This reach has a greater number of channels than The Key reach, but most are inactive. Typically 2 channels are evident, with a well-defined primary channel. Distinct topographic levels are common for differing channels. A prominent channelised zone is evident within a series of broad sweeping bends. The channel divides around complex, dissected bars but active gravel surfaces are not abundant in this reach, indicating relative channel stability compared with upstream reaches. Tributaries in this reach, including Waituna, Elm Tree and Bridge Creeks, are not active at present and have minimal impact on river morphology. The channelised zone is densely vegetated with mature willows, gorse and broom. Many willows are observed mid-channel.

Fern Hill reach extends from the bedrock constriction on the right bank at Fern Hill to the downstream margin of Mt York. The Whitestone River is the main tributary in this reach. Although laterally confined at the head and

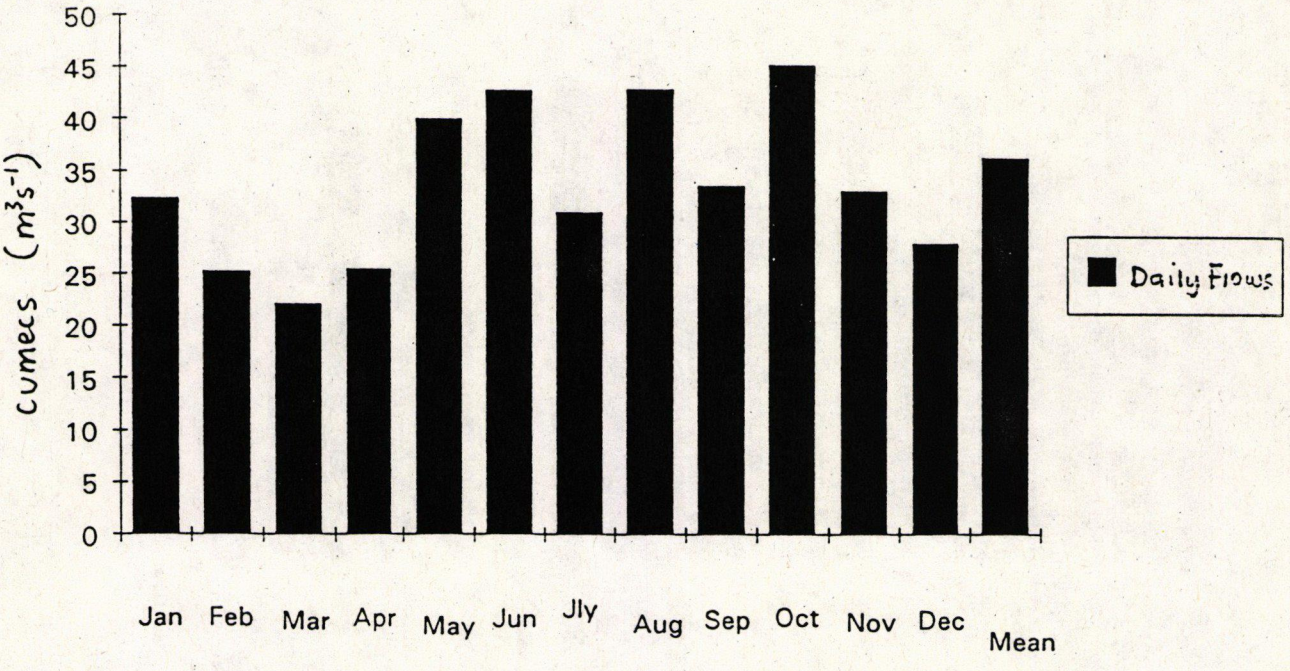
tail of the reach, Fern Hill reach is characterised by extensive gravel surfaces contained within a well-defined channel zone. This reach is differentiated from the Wilderness reach by a greater abundance of active gravel surfaces, which can be attributed to the input of gravels from the Whitestone River. The bars, banks and alluvial flats continue to be vegetated by willows, gorse and broom, however, this vegetation is less dense than along the Wilderness reach.

Riverslea Confinement reach is a single-channelled reach that extends from downstream of Mt York to the Mararoa Weir at the confluence of the Waiau River. This reach is characterised by a series of tightly confined bends that flow within cemented outwash deposits and bedrock. As the river enters the Waiau Valley lateral constraints are removed. The reach appears to be an effective conveyor of fine gravels which are accumulating at the weir. Valley sides and alluvial flats are vegetated with gorse, broom, cabbage tree, fern and toi toi; and bars and banks with gorse, broom and the occasional willow.

3.7 HYDROLOGY

A water level recorder was installed on the Mararoa River in April 1976 at Cliffs, a site just upstream of the Manapouri-Blackmount bridge. Hydrology data was recorded from 1976 onwards, and in the period from 1977 to 1992 the mean daily flow was 33.7 cumecs. The maximum flow recorded is 666.6 cumecs on 16 August 1991 and the minimum flow is 4.2 cumecs on 26 August 1976. On average, flows are highest in early winter (May and June) and early spring (August and October), and lowest in early autumn (February, March and April) (Riddell et.al., 1992;3-37). Annual and monthly average discharges are presented in Tables 3.7-1 and 3.7-2, and magnitude/frequency of flood events in Table 3.7-3.

Graph 3.7-1
Mararoa River monthly discharge means, 1976-1993



Graph 3.7-2
Mararoa River annual discharge means, 1976-1992

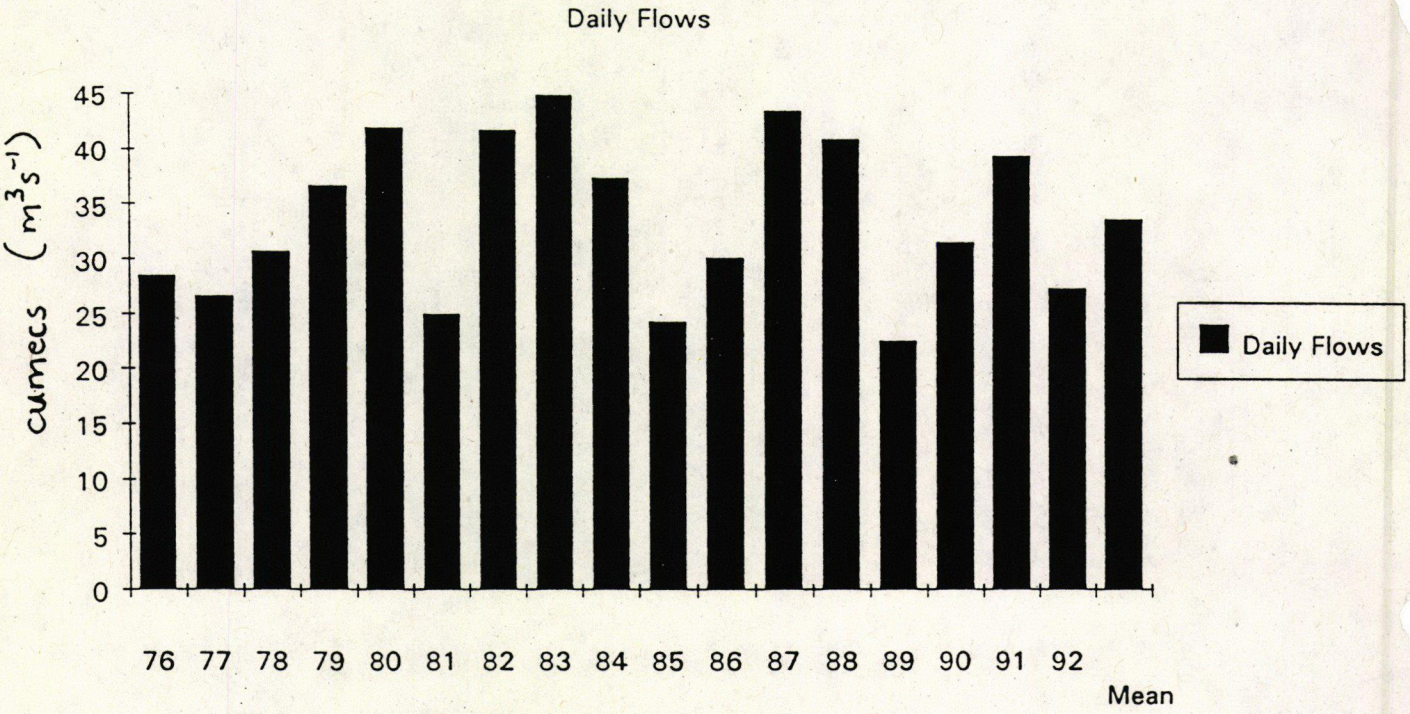


TABLE 3.7-3

Magnitude / frequency of floods on the Mararoa River, 1976-1992.

DATE	DISCHARGE	RANK	ri
June 6, 1976	143.8	17	1.1
Oct.30, 1977	328	8	2.3
May 31, 1978	418.7	5	3.6
Jan.28, 1979	256.5	10	1.8
Aug.26, 1980	557.5	2	9
Apr.26, 1981	202.3	11	1.6
May 22, 1982	409	6	3
Jan 13, 1983	467	4	4.5
Jan.27, 1984	468.3	3	6
Jan.23, 1985	152.5	15	1.2
Jun.13, 1986	181.1	12	1.5
Mar.10, 1987	345.4	7	2.6
Sep.13, 1988	318.1	9	2
Mar.10, 1989	147.6	16	1.1
May 14, 1990	159.3	14	1.3
Aug.16, 1991	666.6	1	18
Oct.21, 1992	166.6	13	1.4

Correlation between rainfall and hydrology data sets is limited by various factors. The Mavora Lakes act as storage reservoirs on the Mararoa River and their influence is such that most floods tend to last for several days. In comparison, the tributary streams of the Mararoa River which are not lake-fed have very steep hydrographs. Land use changes have also complicated reliable correlation by contributing to higher peakedness of flows.

3.8 THE IMPACT OF HUMANS

3.8.1 Introduction

The catchment area of the Mararoa River is located in what was one of the more remote regions of Southland. Since the arrival of Europeans in the 1850s the catchment has been substantially modified by human activities. Significant impacts on the river have come from farming, logging, gravel extraction, introduction of animals (deer, possums, rabbits, trout), introduction of plants (willows, broom, gorse), and hydro power development. The Te Anau area, including the Mararoa valley, was

vely developed for farming in the 1960s, and its tourist potential developed. Recreational activities include fishing, picnicking, canoeing, and duck-shooting. The river is renown for supporting a good quality brown trout fishery of regional importance (Anderson, 1992).

3.8.2 Maoris

The Mararoa River was used by the Maoris as a source of food, particularly eels, fish, and waterfowl, and as a route to and from Lake Wakitipu and the Greenstone valley. The name 'mararoa' comes from the maori words marae-, meaning 'open space', and -roa, meaning 'long', referring to the long open plain of the river (Hall-Jones, 1979:54). There is also some evidence of burning in the Mararoa valley by the Maoris. Possible sites of occupation

have been identified but not confirmed (Anderson, 1992; Corry and Puentener, 1993).

3.8.3 Europeans

Prior to the 1850s, European contact with the Fiordland area had consisted of landings by explorers, whalers and sealers on the coastal fringes. In 1854, however, Freeman Jackson and Donald Hankinson journeyed inland to investigate the possibilities of pastoral settlement. By 1861 all readily available pastoral land in the Te Anau Basin was being leased under the Pastoral Licence system. Almost the whole of the Mararoa catchment was held under four or five main titles. The emphasis was on sheep, and by the mid-1860s farming activities were well established.

Problems immediately arose from overstocking and excessive burning, aggravated by the introduction of the rabbit and later the red deer (Dunbar et.al., 1966:10; Williamson, 1990). Isolation and remoteness in terms of physical access and public awareness were further difficulties. In the 1920s a road between Lumsden and Te Anau was built, and a wooden bridge constructed across the Mararoa River at The Key (Woods, 1982:1-4). In March 1935 the bridge was severely damaged in a flood and a new concrete bridge was completed in 1937 by Public Works (now Works Consultancy) (Boniface, pers.comm.).

In 1953 the Lands and Survey Department took up most of the land in the Mararoa catchment and implemented a policy of land development. Together with other small areas of Crown land, it made an area in excess of 103,000 hectares, one of the largest land development projects in New Zealand (Mills, 1989, p.29). A land use capability survey of the catchment was undertaken by the Soil Conservation and Rivers Control Council and

completed in 1961. The report recommended that the lower part of the catchment be used for intensive pastoral farming, with the use of supplementary forage crops (Dunbar et.al., 1966:9-11, 37).

3.8.4 Lake Manapouri Hydro-Electric Scheme

In 1904 the region was considered as a possible source of hydro-electric power, but the scheme was not proceeded with because of the inaccessibility of the area and the magnitude of the project. In 1959, however, the scheme was revived, principally as the result of a proposal to construct an aluminium smelter on Tiwai Point in the Bluff Harbour. This culminated in the Manapouri-Te Anau Development Act 1960. Investigations were initiated by Comalco Industries Proprietary Limited of Australia (formerly Consolidated Zinc) and subsequently taken over by the New Zealand Government in 1963.

Water was diverted out of a new outlet from West Arm into Deep Cove, Doubtful Sound, and a powerhouse was built out of solid rock beneath the lake with a 10km tailrace tunnel to the sea at Deep Cove. The final stage of the project involved the building of control structures on the outlets of both lakes; the Te Anau structure was completed in 1974 and the Manapouri structure in 1976 (Pickrill and Maciver, 1978, p.9). The Manapouri Lake Control dammed the Waiau River slightly below the confluence of the Waiau and Mararoa Rivers so that the Mararoa River flowed back into Lake Manapouri.

As a consequence of the hydro power development on Lake Manapouri the natural flows of the Waiau River have been significantly altered, and to a lesser extent affected flows in the lower course of the Mararoa River (Woods, 1982). Deterioration in fish numbers and size has been noted since

the weir was constructed, as sea-run fish are prevented from returning to the river (Anderson, 1992).

3.8.5 Introduction of willows

A large flood in 1949 took out the abutments to the Key Bridge and extensive protection works were carried out by Public Works on both banks upstream of the bridge. This involved construction of stopbanks, groynes and rock walls, which were pole planted and anchored with crack willow, with work completed in 1950 (McGregor, pers.comm.; Galland, pers.comm.). Willows were anchored by being laid along the river bank with butts upstream and tied to a main cable. The trees are weighted down to ensure they do not rise with the river and break away. Pole plantings comprise of 3m long unrooted willow poles which are dug into banks to provide a line growth that will protect the banks (Clarke and Daniel, 1986; McGregor, pers.comm.; Jarvie, pers.comm.).

Bank protection work was also carried out above the Mararoa Bridge and Princhester Farm Settlement by the Southland Catchment Board in 1960s. The property is located on the right bank of the Mararoa River, immediately downstream of The Key Bridge. A large flood in early 1967 caused damage to fences and pastures located adjacent to the river. A large groyne was erected and supported by a stopbank, and pole planted with crack willows (H. McDonald, pers.comm.). Subsequent work was carried out after a flood in 1984 to strengthen the rock groyne (Barker, pers. comm.).

The willows quickly spread downstream, contributing to minor flooding problems on properties adjacent to the river (Barker, pers.comm.; Chartres, pers.comm.; Gunn, pers.comm., H.MacDonald, pers.comm.). In the early 1970s the Catchment Board recognised that there was a serious problem with

uncontrolled growth of crack willows, due to its ability to spread rapidly from broken branches. Potential for willows, gorse and broom to spread to Lake Manapouri and the Deep Cove area was also recognised (Woods, 1982). In 1975 a spraying programme was proposed on the Mararoa River to eradicate crack willow; and consisted of aerial spraying of willow growth and manual spraying over 3 years, for a 15 km length on the Mararoa below The Key Bridge (Southland Regional Council, 1973). However, the programme never went ahead due to lack of government funding. Another programme was proposed in 1984 for aerial spraying of willows, gorse and broom above the bridge and work commenced in 1986. The programme was taken over by the Department of Conservation in 1989 and has been relatively successful (Spittle, pers.comm.). Spraying below the bridge was not considered due to insufficient funding (Rance, pers.comm).

3.9 SUMMARY

The Mararoa is typical of many New Zealand rivers in that it has abundant, coarse, non-cohesive bed-load, a fluctuating flow regime and steep slopes. Abundant sediment derives from a series of actively eroding glacial outwash terraces along the course of the modern river. The present character of the Mararoa River is an artefact of regional history, reflecting the antecedent controls of tectonic uplift and glacial deposits on channel condition.

As a result of human modification the original cover of tussock on the floodplain was replaced by crack willows. The willows quickly colonised the active bar surfaces and stabilised this reach of the river. Changes in channel planform occurred, resulting in localised flooding and potential disruption to hydro-power production.



PLATE 3.9 - 1
Manapouri Station, early 1900s



PLATE 3.9 - 2
Stage-coach crossing the Mararoa River at The Key, 1890s
No bridge exists at this time, so the Mararoa River could only be crossed in low flows. The vegetation of the banks and floodplain is dominated by tussock.
From Hall-Jones (1979)

CHAPTER FOUR - METHODS

4.1 REACH SELECTION

River reach analysis was carried out on the Mararoa River from the outlet of South Mavora Lake to the confluence of the Mararoa River and the Waiau River in January 1993 (Brierley, 1993). The procedure, as used by Brierley (1992, 1993), provides an appropriate basis for base-line inventory of channel condition. It is an integrative approach to understanding river behaviour and is applied at three scales of analysis, the valley scale, the channel scale and the bar scale.

From the 1993 survey of the Mararoa River a particular reach was chosen as a case study reach to investigate the impact of vegetation on channel adjustment. The selected reach is named the Wilderness Reach by Brierley (1993), and extends from The Key Bridge to the bedrock constriction at Fern Hill (GR 105060 to GR 034064 on the Te Anau (D43) 1:50000 map). The reach has an extensive valley flat unconstrained by bedrock, although terrace features place some constriction on lateral movement of the river. There are no large tributaries in this section of the river, with the influence of several small tributaries on channel planform being insignificant.

These features are similar to those found along the Haycocks reach. The Haycocks reach still has much of its native cover of tussock, whereas dense growths of willow, gorse and broom have replaced the native vegetation of tussock in the Wilderness reach. Willow growth in this reach can be traced back to known introductions of willows in 1950 and 1967. It is assumed that the Wilderness reach once resembled the Haycocks reach with its laterally unstable, low sinuosity channels. The Haycock reach has 4-6 active channels with large active bar surfaces and frequent inundation of channel-marginal

flats by secondary channels, compared to 2-3 stable, sinuous channels along the Wilderness reach.

Factors supporting reach selection included the availability of rainfall data and aerial photograph coverage. Rainfall data has been collected since 1952 at The Plains Station, located at the head of this reach on the left bank. As hydrology data was only collected since 1976, rainfall data is useful in interpreting the flood history in the period from 1952 to 1976. The availability of aerial photographs that predate the introduction of willows and, show the gradual expansion of the area covered by willows, is essential to this study.

4.2 PHOTOGRAMMETRIC ANALYSIS OF CHANNEL CHANGES

4.2.1 Photogrammetric techniques

Photogrammetric analysis of aerial photography from 1948, 1957, 1970, 1979, 1987 and 1991 was undertaken to investigate temporal planform adjustments of the channels in the lower course of the Mararoa River. In combination with data obtained from site analysis in the field, results of the photogrammetry allowed evaluation of the role of vegetation in influencing channel adjustments.

Vertical aerial photograph sets were obtained from New Zealand Aerial Mapping LTD and Southland Regional Council. These were the only sets available of the Mararoa River. Coverage is not complete, with 1948 run not reaching The Key Bridge, and the 1979 run having fragmentary coverage around the Fern Hill area.

Channel position in the period from 1948 to 1991 for the reach under review was drawn using a mirror stereoscope. Glacial outwash terraces were used as

the main control points, with State Highway 94, The Key Bridge and minor roads and tracks serving as suitable cultural features for mapping. These control points appear on the 1989 topographic map (Te Anau 1:50 000) and all the photo sets.

Channel sinuosity and number of channels was determined for each photo run. A traced overlay from each photo set was then produced so that channel change in this period could be assessed. To assess channel changes at the field sites cross-sections of the floodplain between the main terraces were drawn for each photo set. Fluctuation in channel width was recorded at each site, similar to the technique used by Beshcta (1983). Channel adjustments throughout the period were related to the flood history.

4.3 SITE ANALYSIS

4.3.1 Site selection and framework for analysis

Sites were selected after detailed analysis of bar types from topographic maps and aerial photographs. Selected sites are well-spaced so assessment could be made of spatial adjustments in channel form. A range of bar surfaces were selected to represent the range of bar types in the field.

Sites 1 and 3 were modified by river protection works carried out in 1949-50 and 1966 respectively. These are the sites where willows were introduced, so all subsequent willow growth can be traced back to these sites. Site 2 is an abandoned channel lined with willows. Aerial photographs reveal that this abandonment is relatively recent (change has occurred prior to 1987). Sites 4 and 5 are paired sites. Site 4 is located on the principal channel and Site 5 on a secondary channel. They are divided by a large island that is densely vegetated with willows. What is of particular importance is that a switch in channels has occurred since

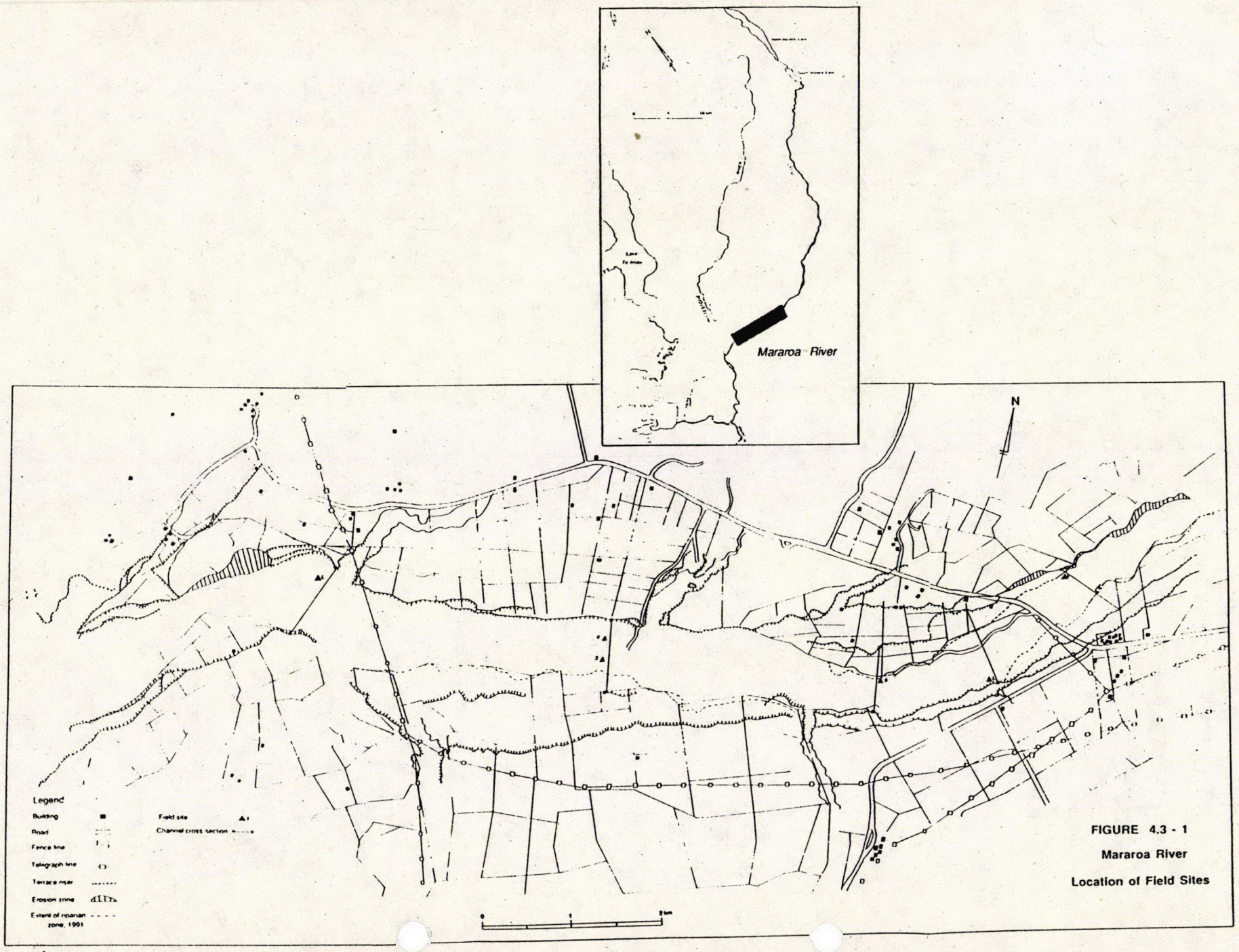


FIGURE 4.3 - 1

Mararoa River

Location of Field Sites

the last aerial photograph was taken in December 1991. Similarly, Site 6 is also an abandoned channel which was a principal channel in the 1991 aerial photographs.

The main objective was to examine the role of willows in channel adjustment at these sites. This was achieved through the examination of geomorphic units on bar surfaces, the location of willows in relation to these geomorphic units, and the age of willows at the different sites.

4.3.2 Geomorphic units

To explain where, how and when willows interact with rivers, the location of willows on bar surfaces was related to local scale depositional features. These features are termed geomorphic units in this study, but were termed architectural elements by Miall (1985) and morphostratigraphic [illegible] by Brierley (1991). Brierley (1991) found that the mechanisms [illegible] on these units were consistent regardless of the broader scale environmental setting. The analysis of geomorphic units on bar surfaces provides a reliable basis for determining depositional environments, as they directly relate form and process (Brierley, 1991).

Five units identified on the Mararoa River were alluvial flats, chute [illegible] bar platforms, channel marginal surfaces and ridges, as based on those defined by Brierley (1991). Alluvial flats were defined as well vegetated depositional units with relatively flat surfaces. Chute channels are channels used in high flow stages. They short-circuit the path of the main flow and are of variable cross-sectional form. Bar platforms are plateau-like surfaces typically located next to the channel margin. They are mostly unvegetated, although some bar platforms are gradually being colonised by encroaching vegetation. Ridges are discontinuous raised

TABLE 4.3 - 1

Definition of geomorphic units

Unit	Morphology and scale
Alluvial flats	Densely vegetated unit with little surface relief. Irregularly shaped and sized, with some within-bar units small in size (<25m wide by 25m long) while others are large (>300m wide by 500m long).
Chute channels	Channels of variable cross-sectional form and plan-view outline. Two types are common: cut-offs, which are large-scale channels short-circuiting the path of the main flow, and runnels, which are small, diagonally oriented channels dissecting the floodplain surface. Cut-offs are upto 50m wide with sinuous outlines and variable lengths. Runnels are typically <3m wide and upto 40m long.
Bar platforms	Plateau-like features which are unvegetated or are being colonised by young vegetation. Generally located next to the main channel. May exist as a series of steps, especially on point bars. Can be upto 200m wide by 500m long.
Rides	Narrow strips of deposits observed at channel margins, usually unvegetated. They are elevated upto 3m above the level of bar platforms. Usually linear in outline, or curved on point bars. Generally <20m wide with highly variable length.
Channel marginal	Channel bed features exposed during low surfaces flows. Surfaces are armoured and well-sorted, as fine-grained sediment is winnowed by flows. Surfaces are unvegetated. Size is dependent on flow stage.

Based on Brierley (1991)

mounds, with irregular and elongated outlines found adjacent to river channels. Channel marginal surfaces are channel bed features which are exposed in times of relatively low flow. The material on these units is usually coarse, well-winnowed and imbricated, and can be armoured.

Identification of units was based on surface morphology and geometry, as summarised in Table 4.3-1. Criteria also used in assessment included sediment character, and type and form of vegetation growth. Assessment of sediment character, including sediment size, shape and sorting, lateral and downstream variation, packing arrangement and degree of imbrication, was based on techniques outlined by Gordon et.al. (1992).

4.3.3 Tree ring dating

Dendrochronology is the science of dating annual growth rings in woody plants and the extraction of environmental information that is contained within the tree rings (Shroder, 1980; Butler, 1987). Tree ring dating is used in this study to determine the minimum age of willow establishment on depositional features. Establishment ages of willows can be directly related to flood events as vegetative propagation was the only method of willow propagation on this river. This occurs when branches are broken off in flood events, carried downstream and deposited on bar features in waning flow stages.

Establishment ages therefore assist in dating periods of channel activity and gravel bar development and growth. Establishment ages also document phases of channel abandonment. Correlation of this information with the history of channel change, attained from the aerial photographs, will illustrate the role of willows in channel adjustment along the Mararoa River.

Salix sp. lay down distinct annual rings, resulting from a spurt of growth early in the growing season. Willows are also rapid growing with wide growth rings, allowing precise counting of annual rings (Martens, 1992). The accuracy of dating was confirmed by the trial dating of crack willows (Salix fragilis) planted on a small unnamed creek on Parahau Farm in August 1982. The ten willows that were cored gave dates ranging from 10-11 years.

On the Mararoa River willow trees were selected for dating on the basis of their location in relation to different geomorphic units. Diameter of the main stem was measured using a 2 m diameter tape. A core was then taken at the same position with a 36 cm Swedish increment corer. Minimum diameter of willows selected for dating was 10 cm. Cores were also taken of regrowth stems as evidence of flood events. It was assumed that the multi-stemmed nature of the crack willow did not effect dating methods and that all stems were approximately the same age. Cores were taken at the thickest stem and as close to the base as possible to minimise error.

Limitations of this method included the partial or complete burial of some willows. This meant that only minimum ages of willows could be established. Some overturned trees were buried, so only ages of regrowth stems could be established. Dating of the regrowth can also give a date of when large flood events occurred, a technique detailed by Sigafoos (1964) and Shroder (1980).

4.4 INTERVIEWS

The recorded history of the Te Anau Basin, especially in relation to management of the Mararoa River, is minimal and limited to the development of the Te Anau township. A wide range of people were interviewed to extend

the data base. Interviewees included:

* farmers (thirteen families living adjacent to the river);
* local historians of Te Anau;
* Works Inspector and other representatives from Southland Regional Council;
* a retired Works Overseer for Public Works, Southland;
* a consultant for Works Consultancy, Southland;
* a retired Fisheries Officer for Southland Acclimisation Society;
* representatives from Southland Fish and Game Council;
* representatives from the Department of Conservation, Te Anau and Invercargill;
* Head of Biology, University of Otago, Dunedin;
* Plant physiologist from Crown Research, Dunedin.

Interviewees were questioned on the history of farm development in the area, types of farming activities, impact of flooding on farms adjacent to the river, the role of various groups and agencies in river management, implementation of a river management scheme, use of vegetation in river management, effectiveness of river management strategies, and the future of river management.

Personal observations of the interviewees have been incorporated into the regional setting chapter of this study. Interviewees also aided in site selection through the provision of detailed information of specific sites along the river.

4.4 SUMMARY

An integrative approach to field work and data collection was taken in this study, incorporating aerial photograph interpretation with analysis of geomorphic units on bar surfaces, and tree ring dating of willows. This combination of techniques aims to ascertain whether willows have a significant role in channel adjustment by giving quantifiable data on channel change in the period 1948-1993.

CHAPTER FIVE - CHANNEL ADJUSTMENTS, 1948-1991

5.1 HISTORY OF CHANGE

5.1.1 1948-1957

Channel planform in 1948 is characterised by 5-6 channels with a sinuosity of 1.1. Channels spread widely over the floodplain, although one channel is usually dominant. Instability of channels was evidenced by the extensive bar surfaces, commonly mid-channel features. No willows are evident.

Channel planform in 1957 is characterised by 3 channels with a sinuosity of 1.15. Extensive bar surfaces and mid-channel features give evidence of channel instability. Scattered willows were observed, especially at the upstream end of the reach.

Figure 5.1-1 show significant differences in channel widths and position. The river in the 1957 photos has a much more confined channel zone than shown by the 1948 photos. The 1957 river generally follows the dominant channel of the 1948 river, although there are many places where the channel has shifted through channel incision and widening.

5.1.2 1957-1970

Channel planform in 1970 is characterised by 2-3 channels with a sinuosity of 1.225. Mid-channel bars are still common but point bar features were also commonly observed. By 1970 the alluvial flats were well-vegetated by willows and the channel zone is narrower than in 1957.

Figure 5.1-2 shows some significant shifts in channel position. One example is mid-reach where the 1970 river shifts away noticeably from the 1957 river towards the left bank terrace.

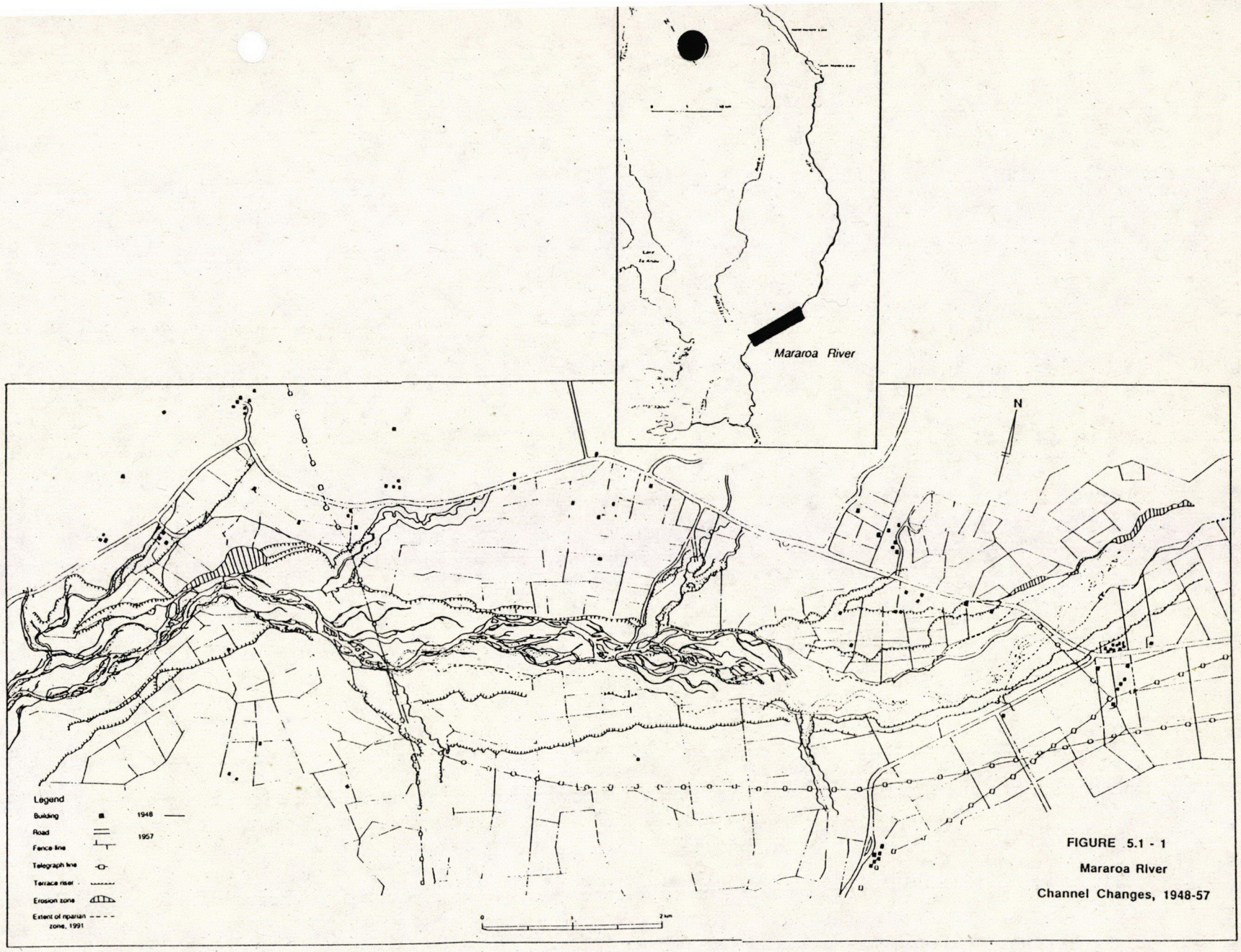


FIGURE 5.1 - 1

Mararoa River

Channel Changes, 1948-57

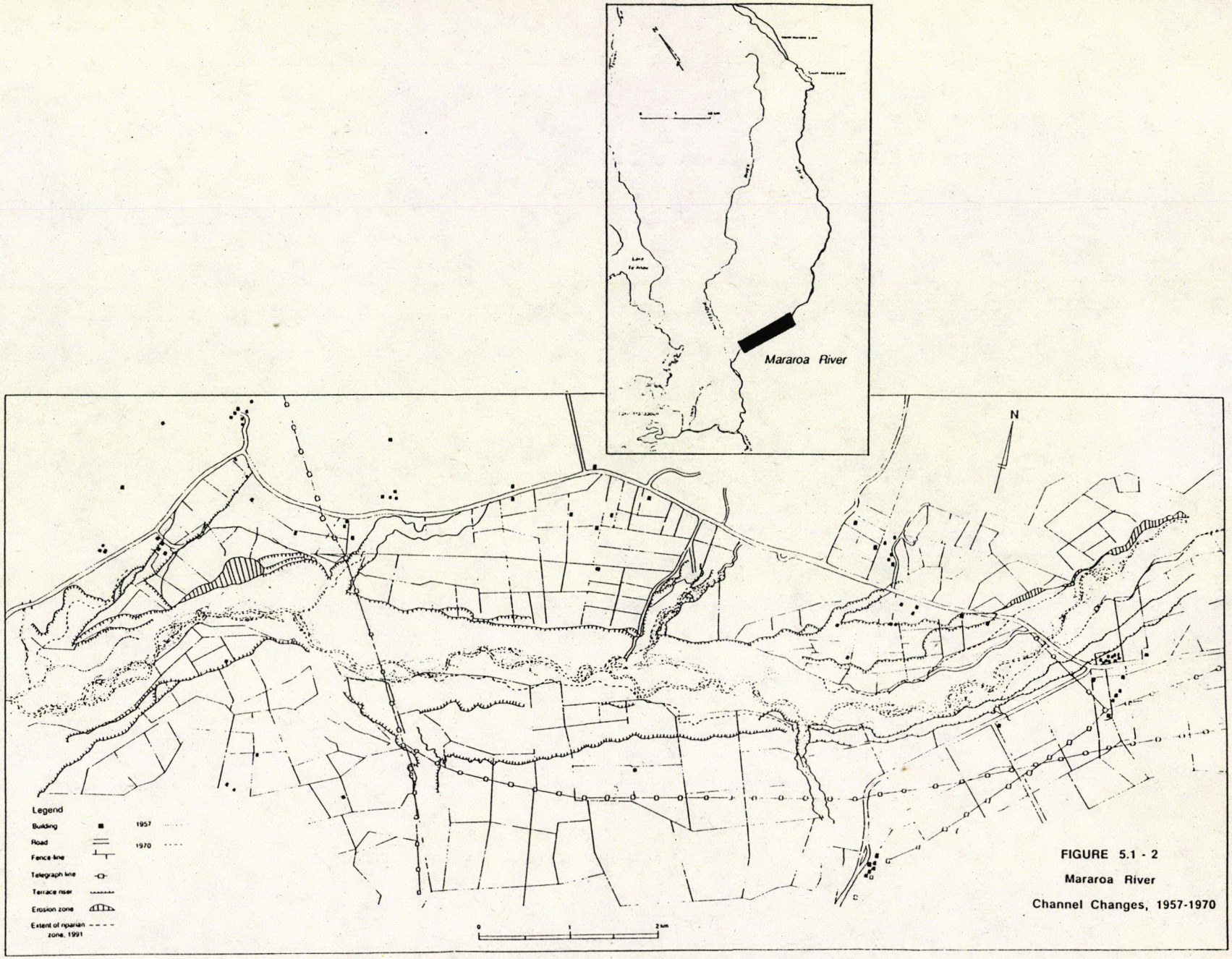


FIGURE 5.1 - 2

Mararoa River

Channel Changes, 1957-1970

5.1.3 1970-1979

Channel planform in 1979 is characterised by 2 channels with a sinuosity of 1.25. Channel stability has increased with many of the mid-channel and point bar features being vegetated by willows. Vegetated islands were becoming more abundant.

Figure 5.1-3 shows that the 1979 river has wider channelised zone than the 1970 river, often with the 1970 river being contained within the channels of the 1979 river. Numerous mid-channel features are shown in the 1979 river.

5.1.4 1979-1987

Channel planform in 1987 is characterised by 2 channels with a sinuosity of 1.3. Fewer mid-channel features were observed than in previous photos. There is a greater abundance of vegetated point bar surfaces. The alluvial flats are densely vegetated by willows.

Figure 5.1-4 shows that channel position is roughly similar in the two photo sets. Incision and widening of channels has resulted in channel migration across the floodplain in some locations.

5.1.5 1987-1991

Channel planform in 1991 is characterised by 1-2 channels with a sinuosity of 1.35. Channel stability is evidenced by vegetated bars and islands. Active bar surfaces and mid-channel features are not abundant.

Figure 5.1-5 shows that the channel zones and positions of the 1987 river and the 1991 river are very similar. This could reflect the stabilised nature of this reach brought about by the willows.

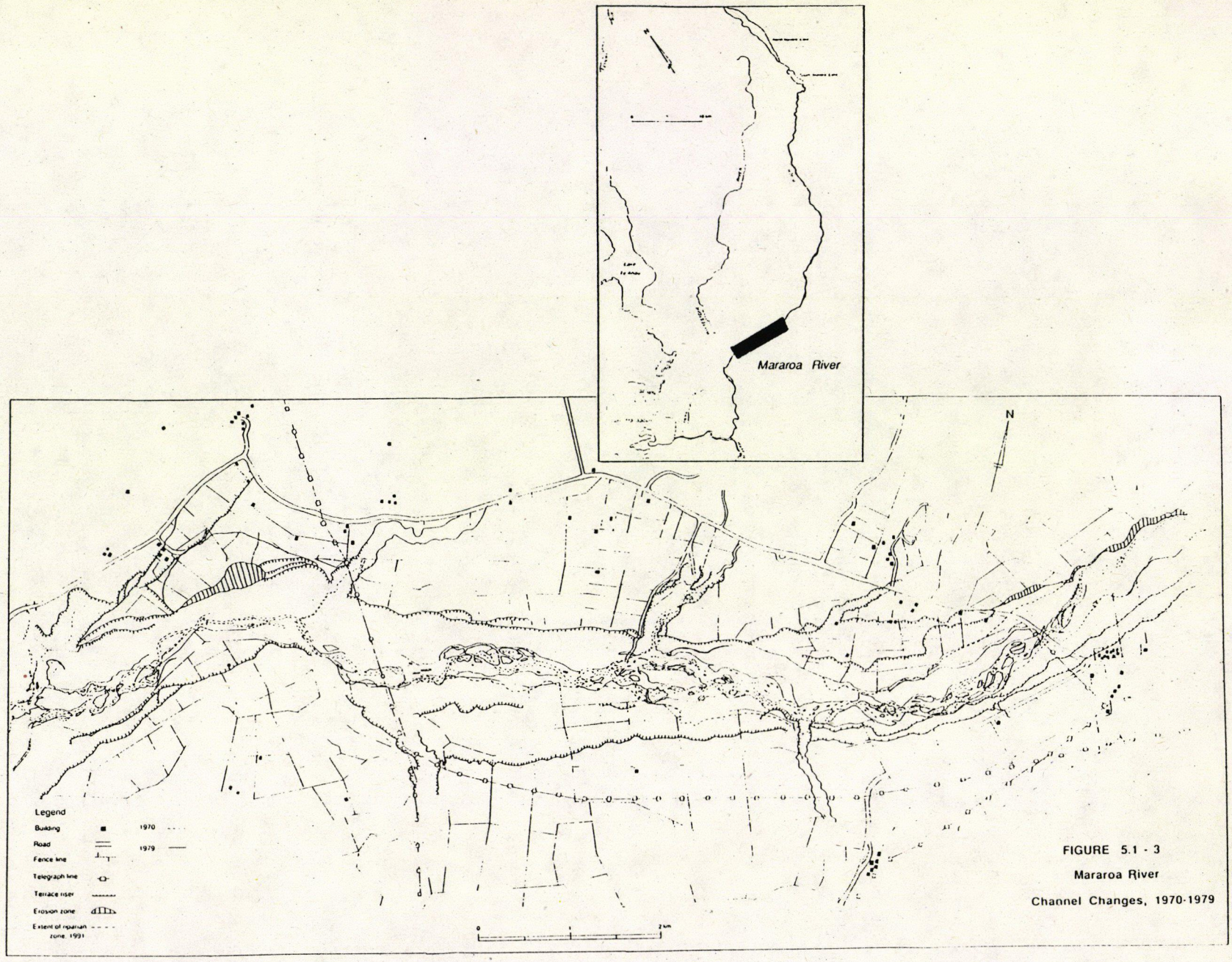


FIGURE 5.1 - 3

Mararoa River

Channel Changes, 1970-1979

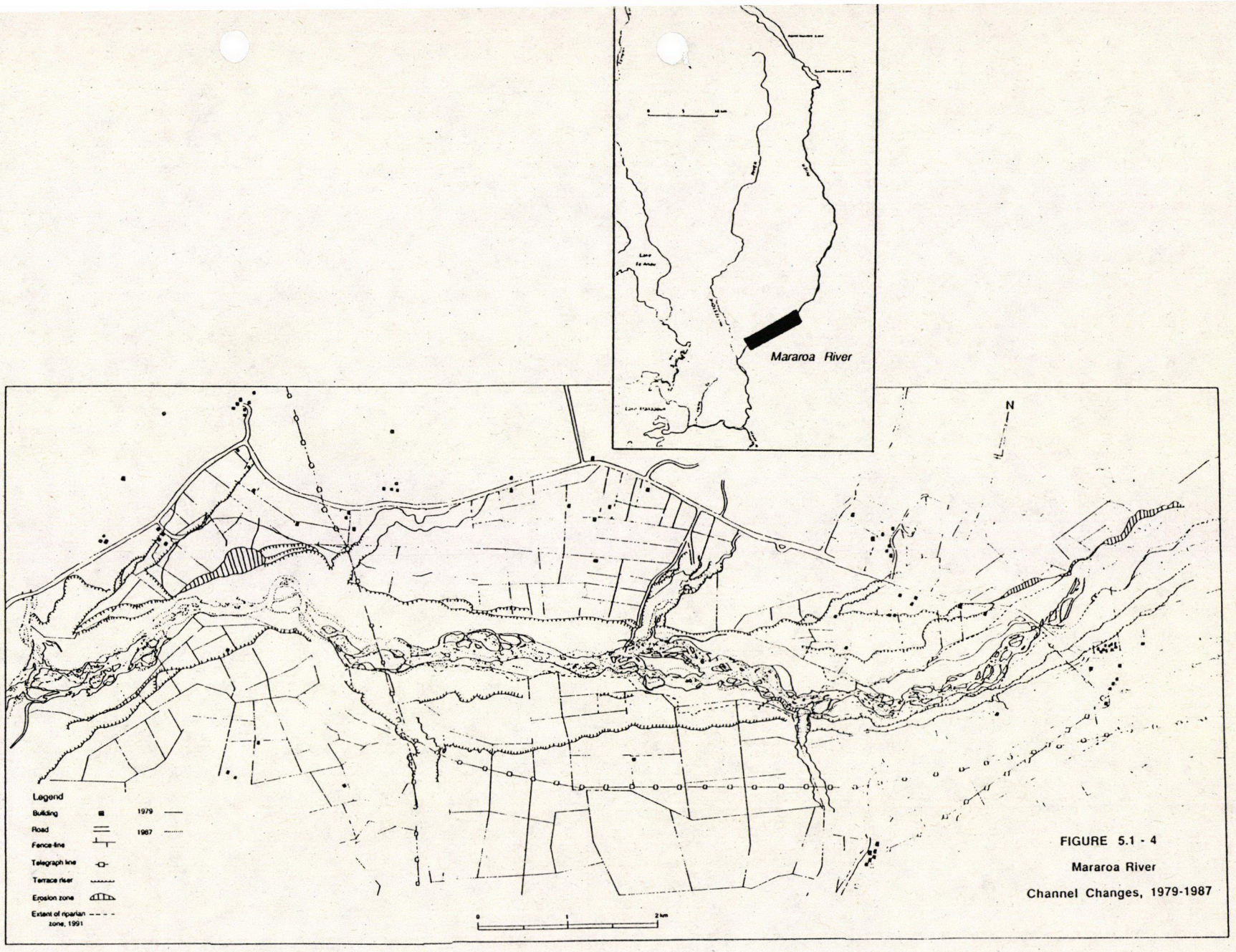


FIGURE 5.1 - 4

Mararoa River

Channel Changes, 1979-1987

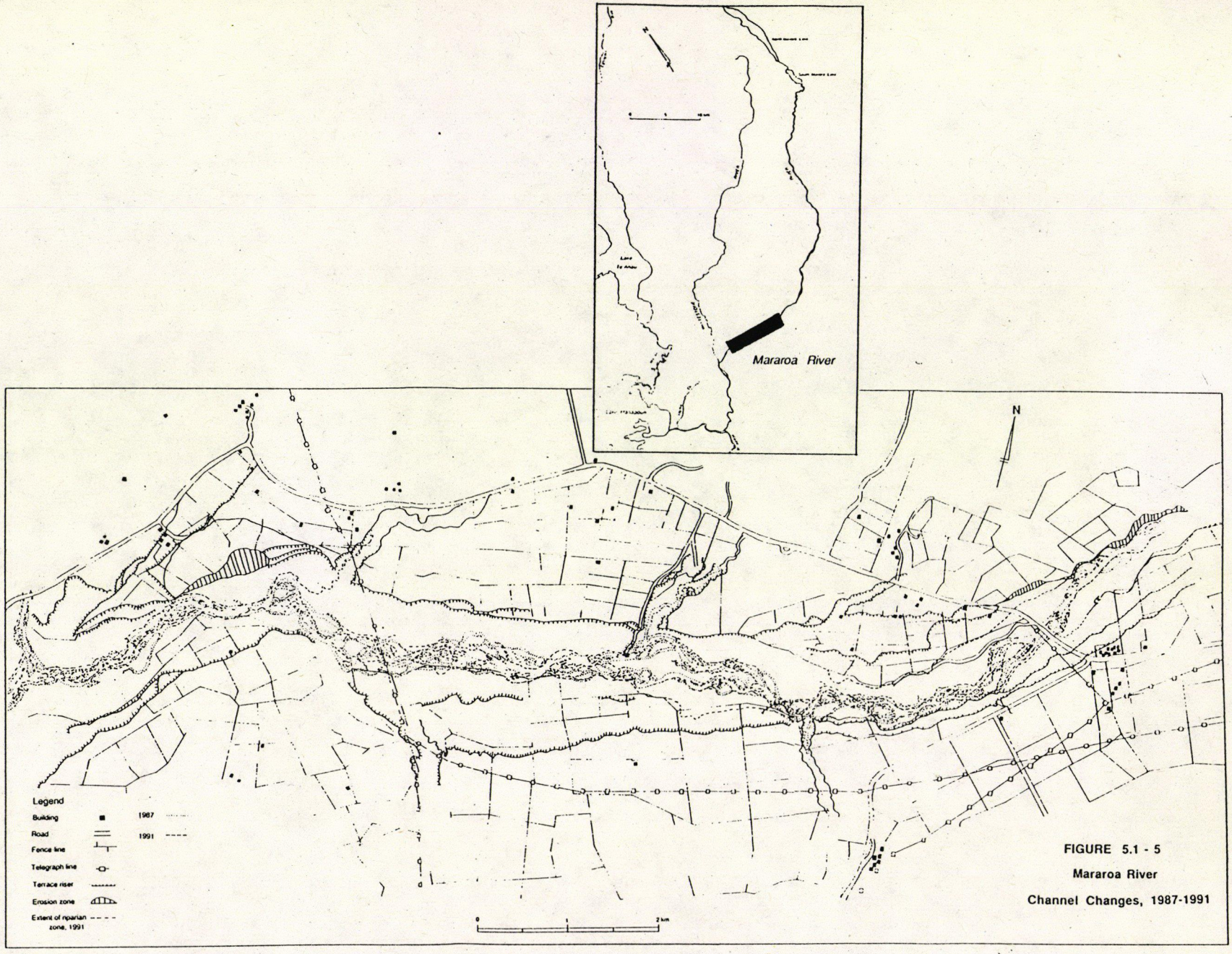


FIGURE 5.1 - 5

Mararoa River

Channel Changes, 1987-1991

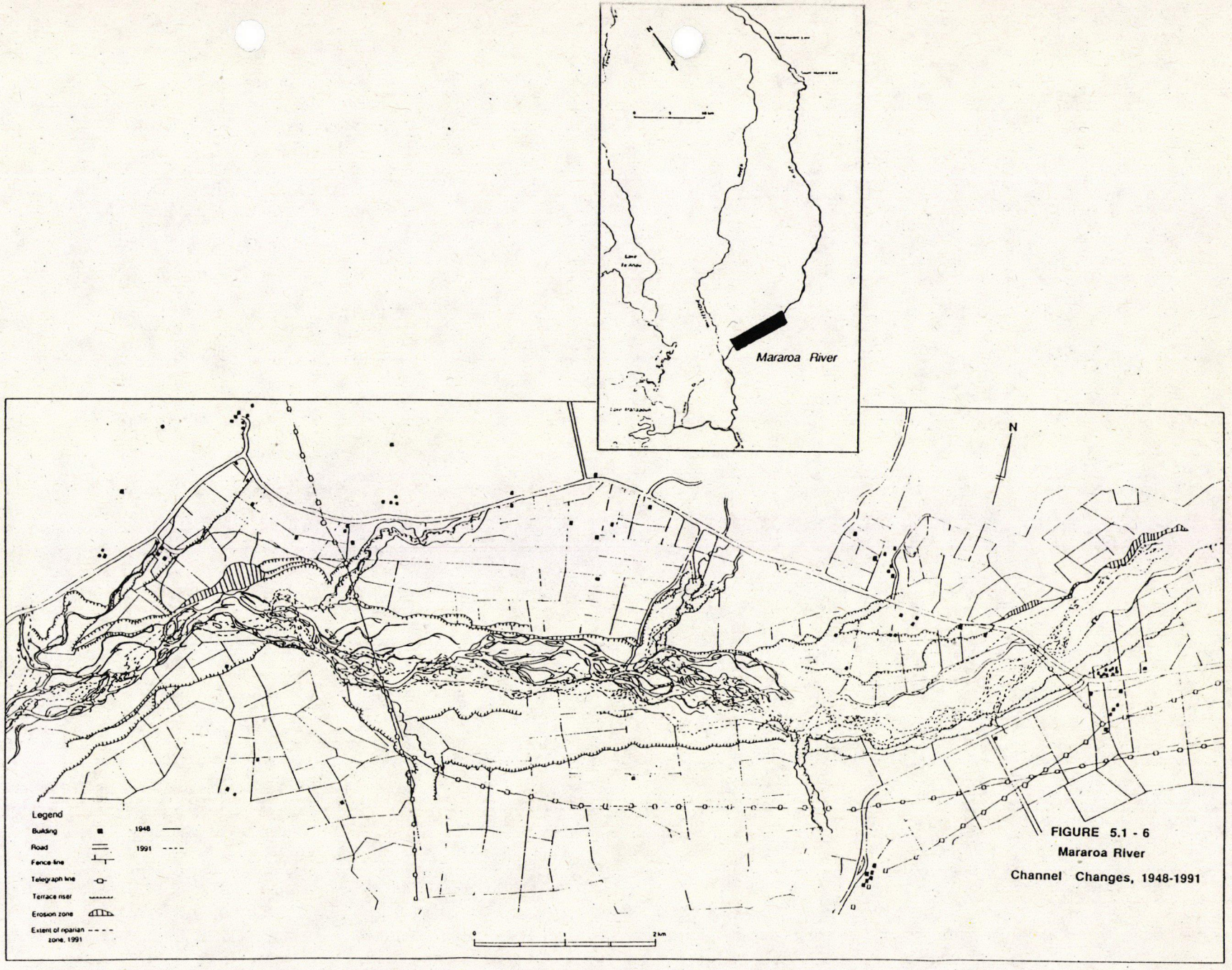


FIGURE 5.1 - 6
Mararoa River
Channel Changes, 1948-1991

5.1.6 1948-1991

River morphology in 1991 is characterised by fewer channels and active bar surfaces than in 1948. In both runs there is generally one dominant channel. The 1948 channels have low sinuosity and the 1991 channel has an irregularly sinuous outline. Bar type has shifted in type from predominantly unvegetated lateral and mid-channel bars to densely vegetated point-bars. This reflects the change in planform from a braided to a wandering style of river.

Figure 5.1-6 shows there has been significant shifts in channel position. In general the 1991 channel has shifted toward the left bank terrace. Most of the channels closer to the right bank terrace have been abandoned.

5.2 RELATION TO FLOOD HISTORY

Dates of the photo runs were related to rainfall data from The Plains Station and hydrology data recorded at Cliffs on the Mararoa. In the case of the 1948 run, rainfall data from Milford was extrapolated to include the Mararoa catchment. However, no date is known for the 1948 run. Milford rainfall data indicates that 1948 was a fairly average year with an annual rainfall of 6283mm (1930-1990 average is 6367mm). Rainfall in December was significantly above the monthly average (897mm compared to the average of 597mm for December).

The 1957 photo run was taken on February 15 1957. The rainfall record shows February as a dry month, with only 22.6mm of rainfall to 15.2.1957. Last rain was 8.1mm on February 13. February is typically a dry month with an average of 77mm. Hydrology data from 1976-1991 shows February as having low daily discharges, with average of 25.2 cumecs compared to annual daily

discharge of 33.9 cumecs. This accounts for the much reduced channel zone in 1957, as compared to the 1948 photo.

The 1970 photo run was taken on February 17 1970. This was also a dry month with 11.2mm of rainfall to 17.2.1957. Last rain was 2.0mm on 13.2.1957.

The date for the 1979 photo run is unknown. The rainfall record shows 1979 as a wet year with an annual precipitation of 1183.4mm, compared to the annual average of 1050.1mm. The hydrologic record also shows 1979 as having high discharge levels. Mean daily flow for the year was 36.7, compared to the average of 33.7. Largest flood occurred on January 28, with a discharge of 256.5 cumecs. This is ranked 10 in annual flood events between 1976 and 1991, with a return period of 1.8 years (see Graph 3.7-3). It is assumed from the aerial photographs that discharge was fairly high as the channel zone in 1979 was much wider than in 1970.

The 1987 run was taken on March 5 1987. Discharge on this day was high at 39.6 cumecs, compared to the average daily flow for March of 22.2 cumecs. Flow on 5.3.1987 is in the waning stages of a flood that occurred in late January, with a peak daily flow of 134.9 cumecs on 28.2.187.

The 1991 photo run was taken on December 18 1991. Discharge on this day was low at 18.6 cumecs, compared to average daily flow for December of 28 cumecs. Last flood of any significance occurred on 18.10.1991 at 131.1 cumecs. Prior to this an extreme event occurred on 16.8.1991 with a discharge of 666.6 cumecs. This is the largest flood recorded in the hydrologic data since 1976 with a return period of 18 years (or longer).

FIGURE 5.3 - 1
Channel changes at Site 1

Width of floodplain = 720m

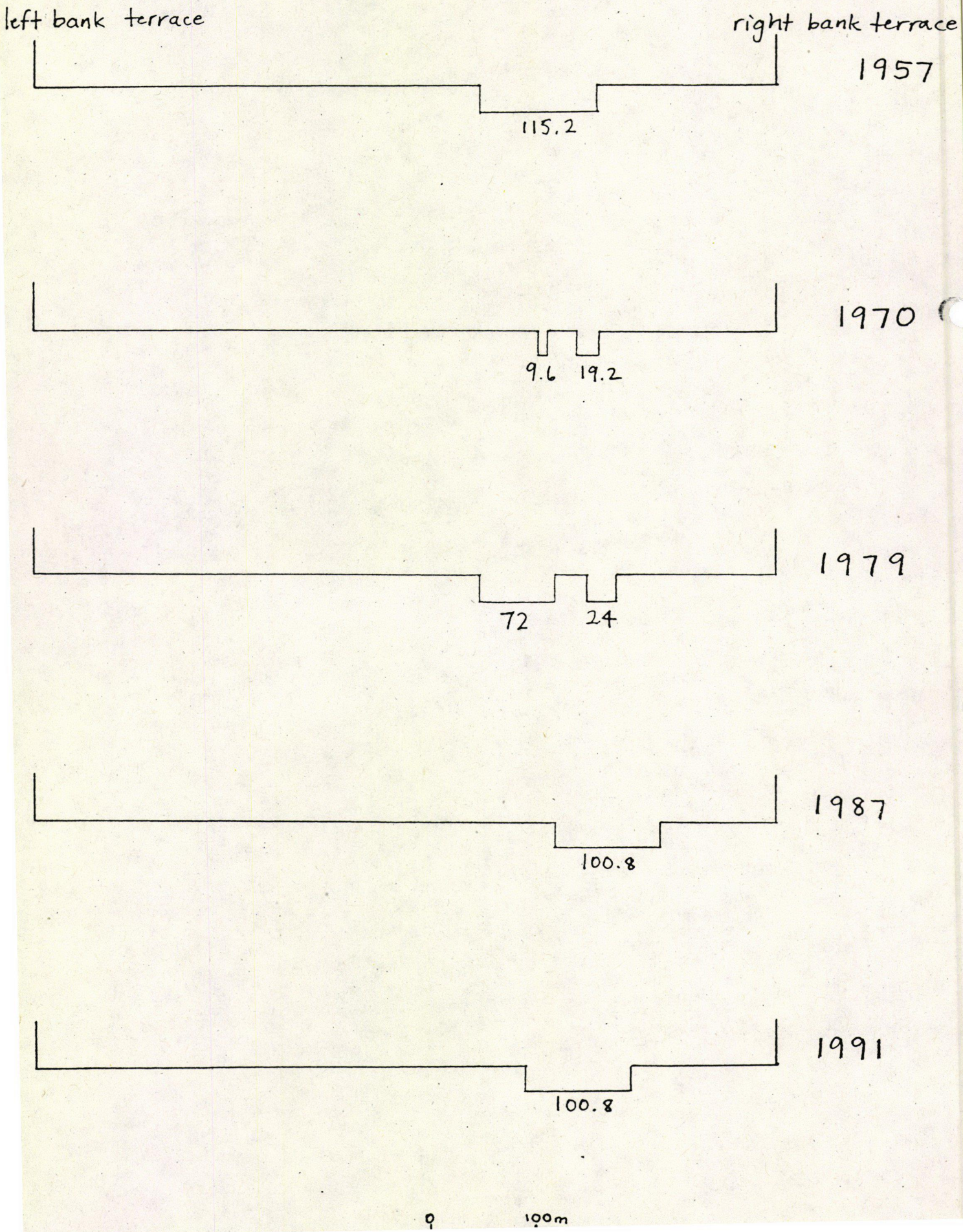


FIGURE 5.3 - 2
Channel changes at Site 2

Width of floodplain = 806m

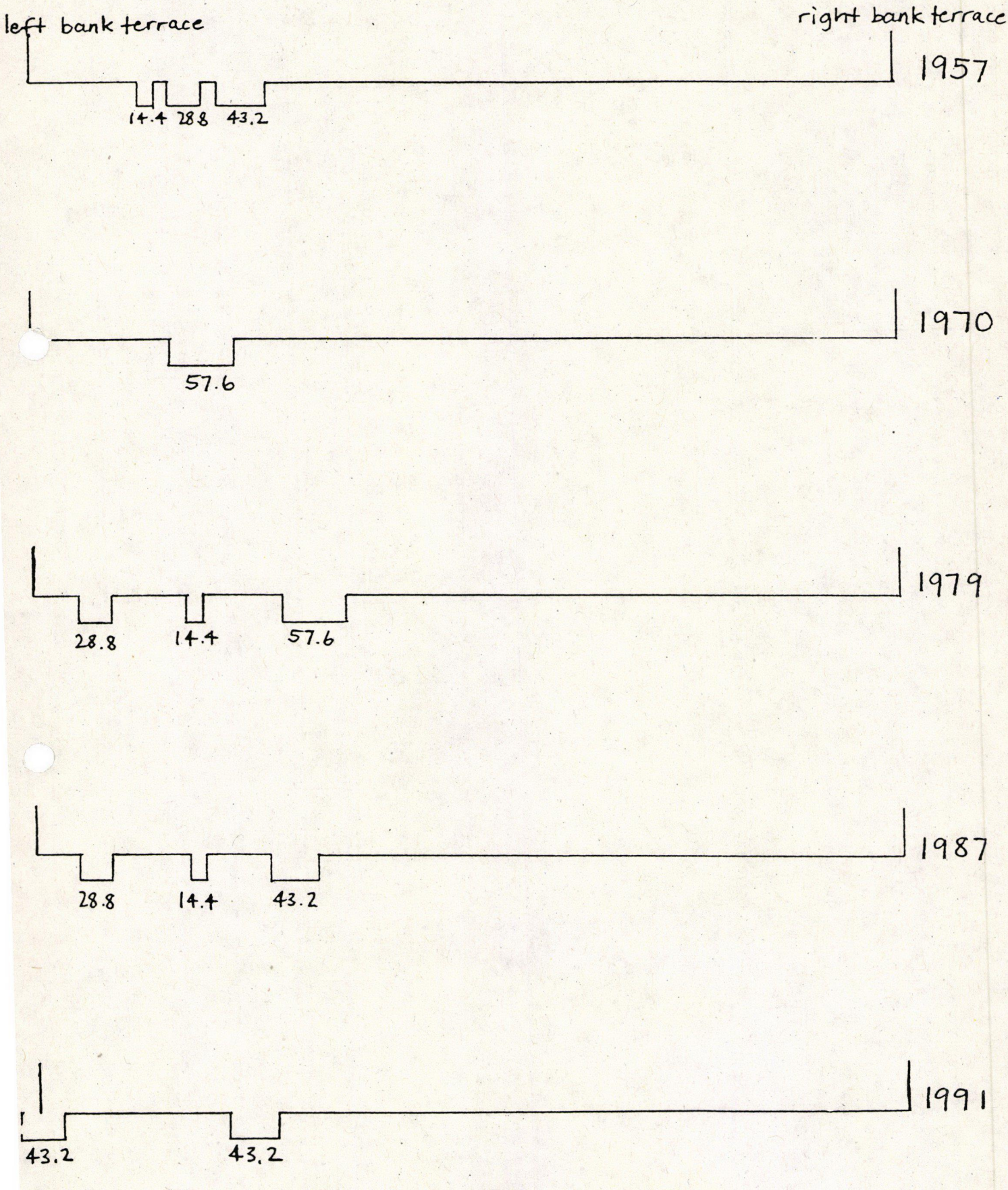


FIGURE 5.3 - 3
Channel changes at Site 3

Width of floodplain = 648m

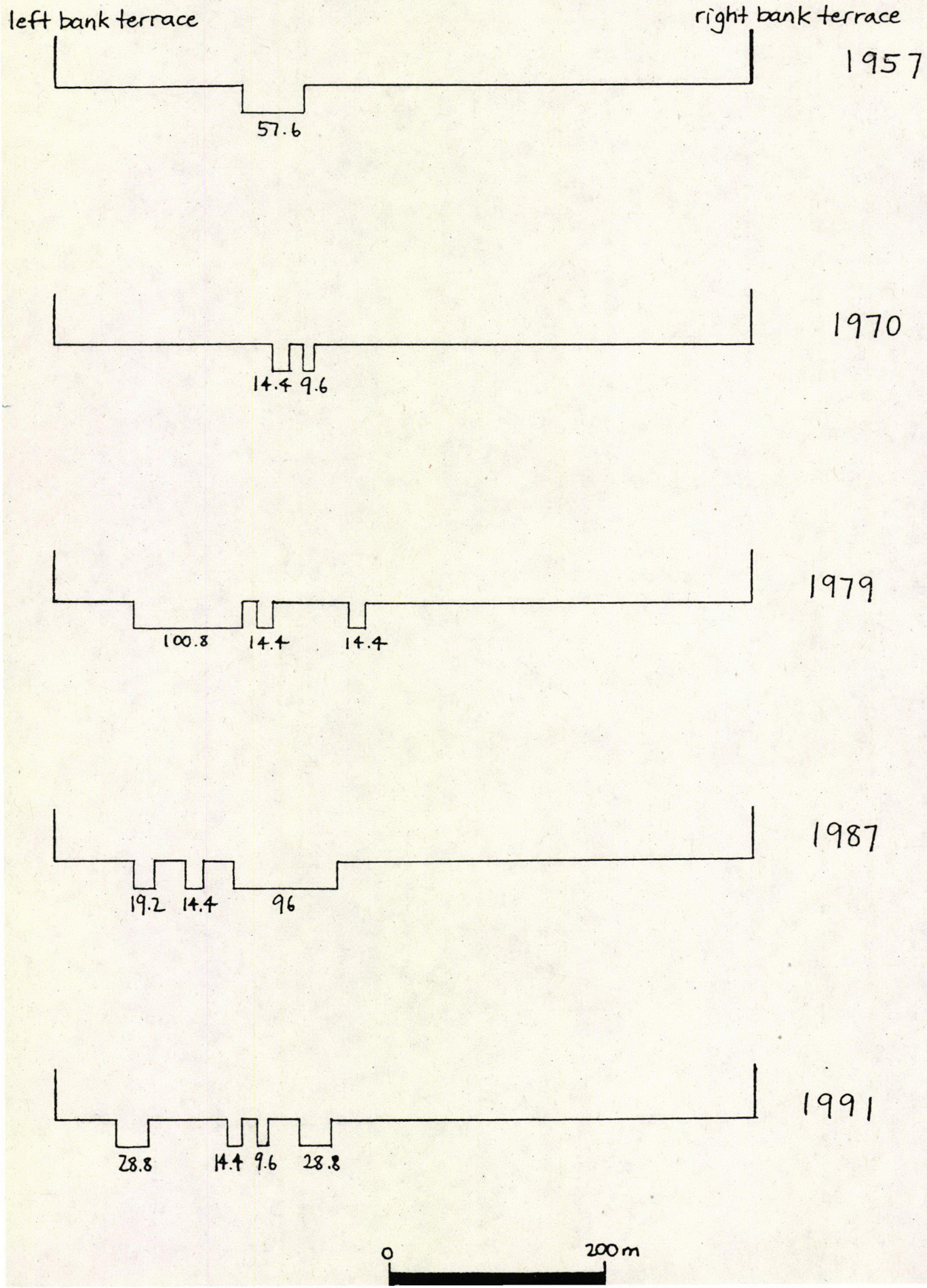


FIGURE 5.3 - 4
Channel changes at Sites 4 and 5

Width of floodplain = 730m

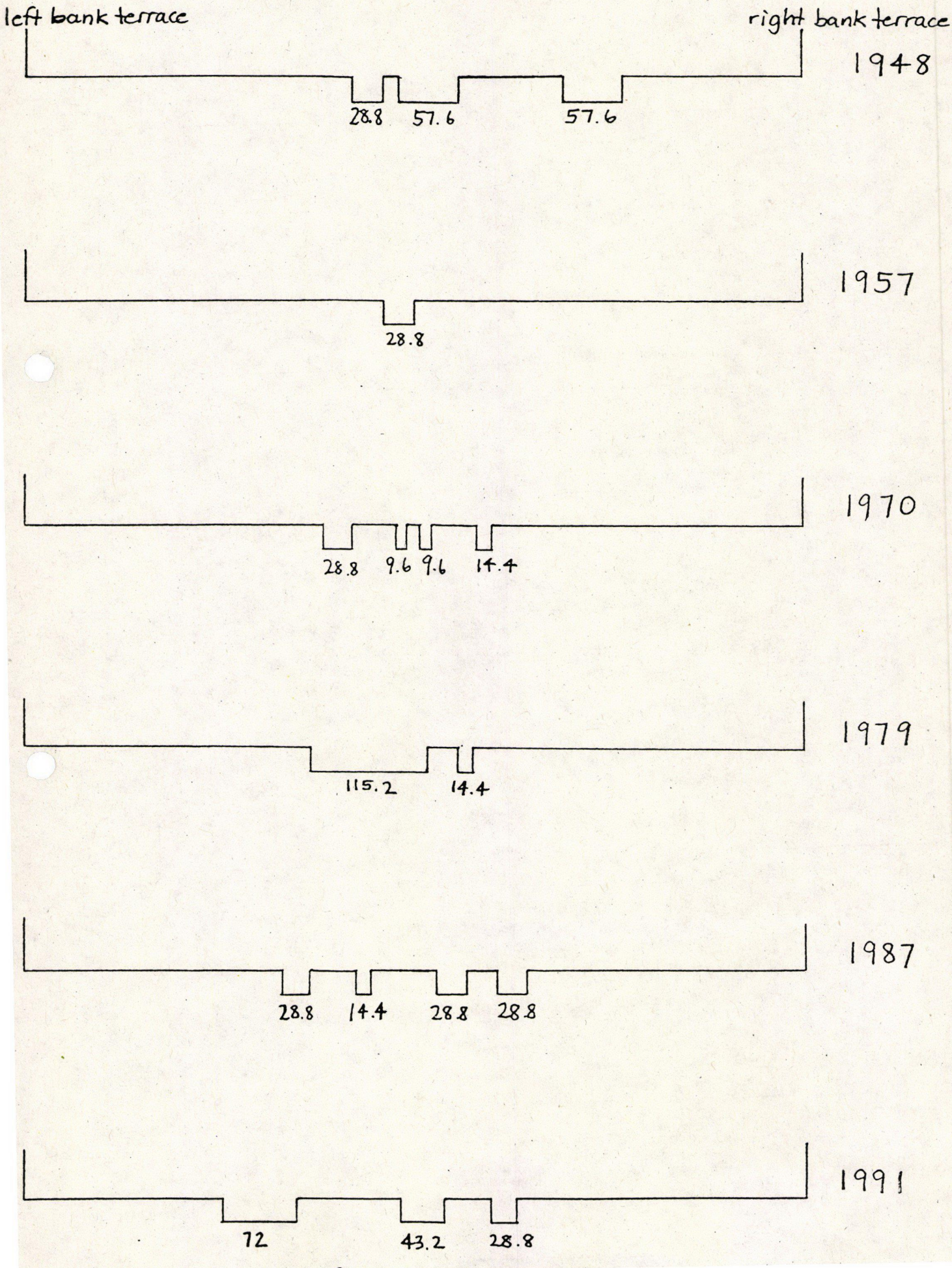


FIGURE 5.3 - 5
Channel changes at Site 6

Width of floodplain = 792m

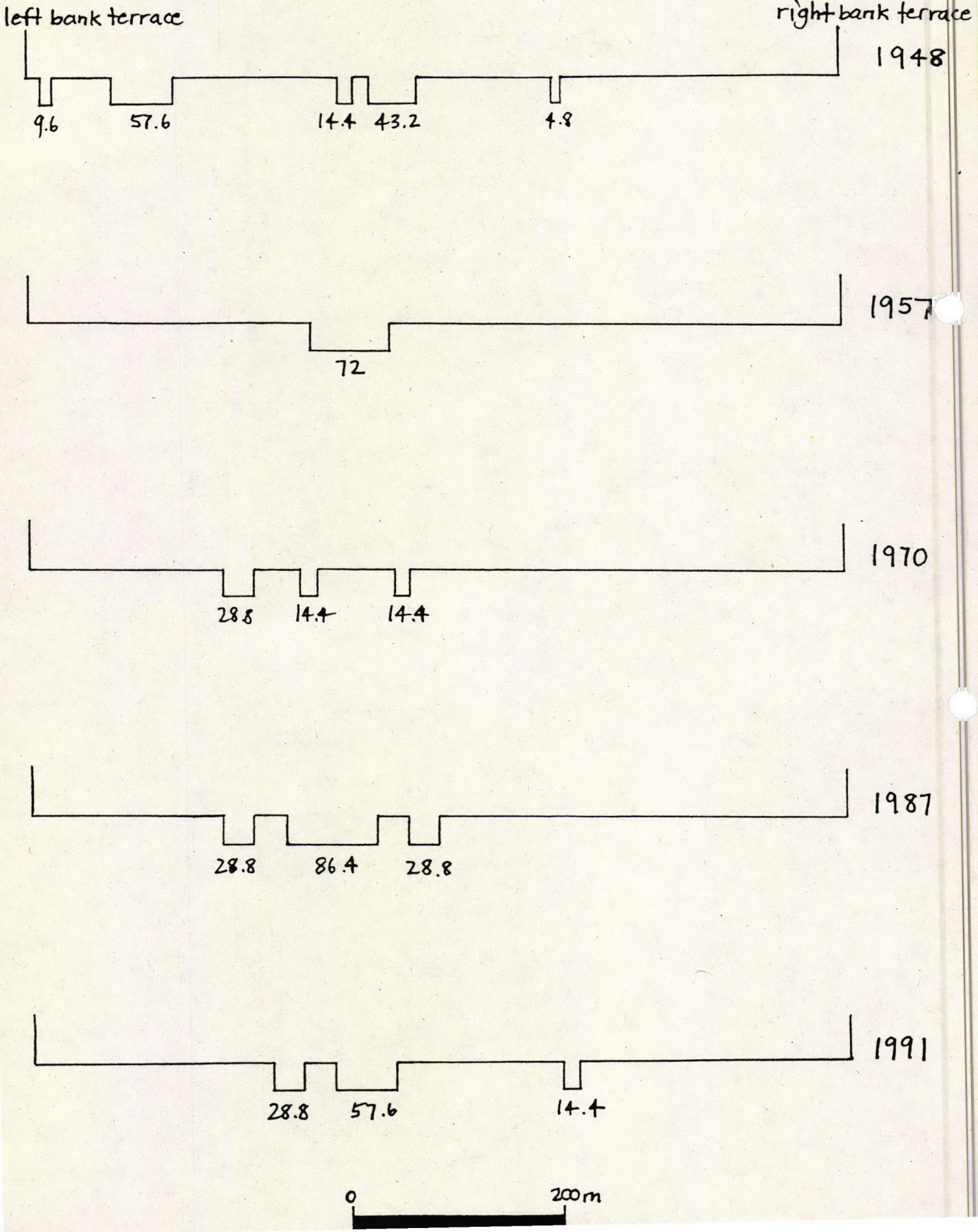


TABLE 5.3 - 1

CHANNEL WIDTHS

SITE No. Floodplain Width		SITE 1 720 m	SITE 2 806 m	SITE 3 648 m	SITES 4 & 5 729.6 m	SITE 6 792 m
1948	(1)	-	-	-	144m	129.6m
	(2)	-	-	-	19.7%	16.3%
1957	(1)	115.2m	86.4m	57.6m	28.8m	72m
	(2)	16%	10.7%	8.9%	3.9%	9.1%
1970	(1)	28.8m	57.6m	24m	62.4m	57.6m
	(2)	4%	7.1%	3.7%	8.6%	7.3%
1979	(1)	96m	100.8m	129.6m	129.6m	-
	(2)	13.3%	12.5%	20%	17.8%	-
1987	(1)	100.8m	86.4m	129.6m	100.8m	144m
	(2)	14%	10.7%	20%	13.8%	18.2%
1991	(1)	100.8m	86.4m	81.6m	144m	100.8m
	(2)	14%	10.7%	12.6%	19.7%	12.7%

(1) = width of channel(s)
(2) = channel width as a percentage of floodplain

5.3 RELATION TO FIELD SITES

Channel widths and positions on the floodplain for each site are shown in Figures 5.3-1 to 5.3-5 and summarised in Table 5.3-1.

The analysis of channel cross-sections shows that the number of channels has varied spatially and temporally according to each site. Shifting of channel(s) is significant at some sites. Development and removal of mid-channel bar features is active, reflecting the dynamic nature of this river system. There is also much spatial and temporal variability in the widths of active channels on the Mararoa River. Unfortunately, results from the channel cross-sections do not show any substantial change in channel width since the introduction of willows. The highly fluctuating nature of channel variables is a response to the highly fluctuating discharge regime and the availability of sediment.

5.4 SUMMARY

The photographic record clearly shows there has been substantial change in channel morphology. A summary of changes in channel planform from 1948 to 1991 is shown in Table 5.4-1. Number of channels has decreased, sinuosity has increased and channel stability has increased.

The flood record shows that the 1957, 1970 and 1991 photos were taken in times of low flow, with greater abundance of bar surfaces and smaller channels than in normal flows. The 1987 photo was taken in a slightly elevated flow stage. The flow stage for the 1948 and 1979 photos is not known, however it appears that the 1948 and 1979 photos were taken at normal to high flow stages.

TABLE 5.4-1

Changes in channel planform, 1948-1991

Year	No. of channels	Sinuosity	Stability
1948	upto 6	1.1	Extensive bar surfaces, especially mid-channel features. No willows.
1957	3	1.15	Extensive bar surfaces, especially mid-channel features. Scattered willows.
1970	2-3	1.225	Mid-channel bars with a few point bars. Alluival flats vegetated with willows.
1979	2	1.25	Mid-channel bars and vegetated point bars.
1987	2	1.3	Fewer mid-channel features, mainly vegetated point bars. Vegetated islands.
1991	1-2	1.35	Fewer mid-channel features, mainly vegetated point bars. Islands and alluvial flats extensively vegetated by willows.

CHAPTER SIX - WILLOW BEHAVIOUR AND DISTRIBUTION

6.1 GEOMORPHIC UNITS

Geomorphic units were found to be consistent in morphology and scale at the different sites, although there were considerable within-bar variability in sediment characteristics. Similar depositional mechanisms appear to be operative on each of the bar surfaces. The primary depositional mechanism on alluvial flats units was flood-related flow processes (Brierley, 1991). Willows and other vegetation trap suspended load material from floods, infilling the existing relief. Vegetation dissipates flow energy and reduces erosive effectiveness of flood flows.

Chute channels are high-energy surfaces which are scoured by fluvial erosion (Brierley, 1991). Sediment in chute channels, which is wide ranging in character, is frequently reworked in high flows. Very little vegetation was observed to be growing in chutes. Debris constrictions sometimes block the chute channel head, resulting in channel abandonment. Conversely, large willow debris can initiate chute channel development when scour occurs around the sides of overturned willows. This highlights the important role willows play in geomorphic unit distribution as chute channels control the spatial pattern of units.

Bar platforms result from within channel processes during high flows (Brierley, 1991). They are normally plateau-like surfaces located adjacent to the channel or to channel marginal surfaces. Small dune features of finer material were commonly observed on their surface. Flood debris and sometimes juvenile species of willow, broom and gorse were seen on their surfaces.

Ridge units were not commonly observed along this section of the river. Ridge deposits accumulate from lateral accretion mechanisms associated with channel shifting (Brierley, 1991). They are hence elongated in the downstream direction in line with the channel margin, and are usually unvegetated.

Channel marginal surfaces are channel bed features which were exposed during low flow stages. They are therefore not strictly bar units. They are typically armoured and well-imbricated, reflecting the stable condition of the channel bed. Sediment is coarse due to the winnowing of fine sediment by flows. In low flows their surfaces are commonly scattered with willow debris, although no vegetation is able to establish permanently.

6.2 DISTRIBUTION AND AGES OF WILLOWS

6.2.1 Site 1

Extensive bank protection works were carried out on this site in 1949-50 after a large flood washed away the abutments to The Key Bridge. Crack willows were pole planted into the rock wall and into groynes for extra stability. These now form a dense stand of mature willows on the northern margin of the site, as shown in Plate 6.2-1. Tree ring dating of 8 willows from the modified bank correctly dated at 39-40 years.

A bank-attached bar has subsequently formed adjacent to this stabilised area, as shown in Plate 6.2-2. Nine willows were dated, with ages ranging from 8 to 20 years old. Willows are located on alluvial flats (3 willows dated at 12, 12, and 14 years), bar platforms (4 willows dated at 8, 12, 20 and 20 years) and on a large chute channel system (2 willows at 12 and 12 years).





6.3.2 Site 2

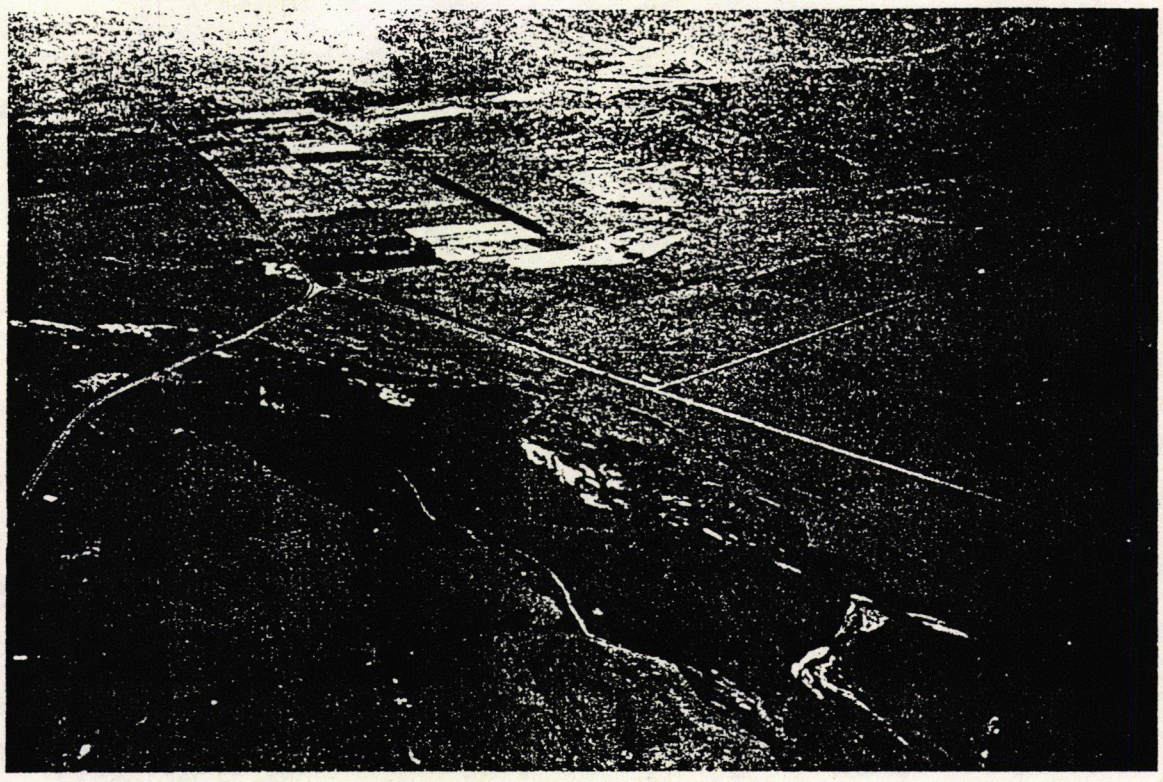
Site 2 is characterised by an abandoned channel lined with mature willows, and a point bar surface which has developed recently beside a large swampy area. The abandoned channel bed has subsequently been re-incised by numerous chute channels. A small tributary, Waituna Creek, joins the abandoned channel on the outside of the loop. This unit is presently being colonised by gorse, broom and grasses. Mature willows are located on the margins of the main chute channel. These are elevated from the channel and were probably once on the banks of the main channel.

Mature willows are also located in the large swampy area which is densely vegetated by willows, gorse and broom. Swampy sections are evidence of old channels which have subsequently been cut-off by vegetation.

Ten willows were dated at this site, with ages ranging from 16 to 36 years. These were located on alluvial flats (16, 23, 26, 26, 33, 36, 36, 36, 36 years) and a bar platform (16 years).

6.3.3 Site 3

Site 3 is a complex point bar surface, dissected by several large chute channels. It is also the site where a large rock groyne was constructed in 1967, which was then pole planted with crack willows. A number of willows are located on the margin of alluvial flats units and chute channel units. Ten willows were dated at this site, ranging in age from 14 to 36 years old. The two pole planted willows were dated at 24 years. Others were located on alluvial flats (14, 14, 14, 23, 33, 33, 36 years) and a bar platform (23 years).





6.3.4 Site 4

Site 4 is the first of the paired sites. The paired sites, Sites 4 and 5, are separated by a large vegetated island. Site 4 is a complex bank-attached bar on the right bank of the main channel at the downstream end of the island. There is an extensive area of alluvial flats which is dissected by a large chute channel. The alluvial flats unit on the central section of the bar is densely vegetated by gorse and broom with the occasional small willow. More mature willows are located on the alluvial flats furtherest away from the channel.

Nine willows were dated at this site, ranging in age from 11 to 23 years. These are located on alluvial flats (12, 14, 20, 20, 23 years), a bar platform unit (14, 14, 20 years), and a channel marginal unit (14 years).

6.3.5 Site 5

Site 5 is located on a secondary channel directly across the floodplain from Site 4. The alluvial flats are well-vegetated with mature willows, broom and gorse, but other units at this site are almost devoid of any vegetation. This suggests that the channel has recently shifted, with vegetation just beginning to colonise this area.

Nine willows were cored at this site, with ages ranging from 8 to 23 years. All willows, with the exception of one willow on a bar platform unit, were located on alluvial flat units. Willows on the alluvial flats were dated at 12, 12, 14, 20, 20, 23, 23 years. The willow on the bar platform was dated at 8 years.



PLATE [illegible]
Silver [illegible]



PLATE [illegible]
Silver [illegible]

6.3.6 Site 6

Site 6 is an abandoned loop of the river. From analysis of aerial photos and field observations it appears that the dense stand of willows at the head of the abandoned channel had a significant role in channel abandonment by deflecting the flow into a secondary channel, which is now the main channel. Dense stands of willows are located on the inside and outside of the loop.

Twelve willows were dated at this site, with ages ranging from 8 to 23 years. These were located mainly on the alluvial flats (14, 14, 14, 14, 14, 20, 23, 23, 23, 23 years), a bar platform (14 years) and a chute channel (8 years).

6.3 SUMMARY

6.3.1 Location of willows

The most mature willows and the greatest number of willows were located on the alluvial flats. These are clearly the oldest depositional surfaces as they are infrequently inundated by flood flows. Willows were also located on bar platform units, but these are less mature and form less dense stands than on the alluvial flats unit. These surfaces are more regularly inundated and reworked by flood events. Ridge, chute channel and channel marginal units were virtually absent of willow growth as these surfaces are regularly active and cannot support the growth of willows or any other vegetation.

Juvenile willows were only observed to be growing on bar platform units. It is assumed that willow branches are washed up on bar platforms in high flows and are left stranded when the flood subsides. As this surface is less frequently reworked by flood flows, willows are able to establish.



PLATE [illegible]



PLATE [illegible]

Willow debris washed up on the alluvial flats is unlikely to sprout due to the shading effect of the large, mature willows. It appears that bar platforms eventually develop into alluvial flat units if they become sufficiently stabilised. This occurs through the process of bank accretion, as willows effectively trap fine material and encourage the growth of banks and bar surfaces.

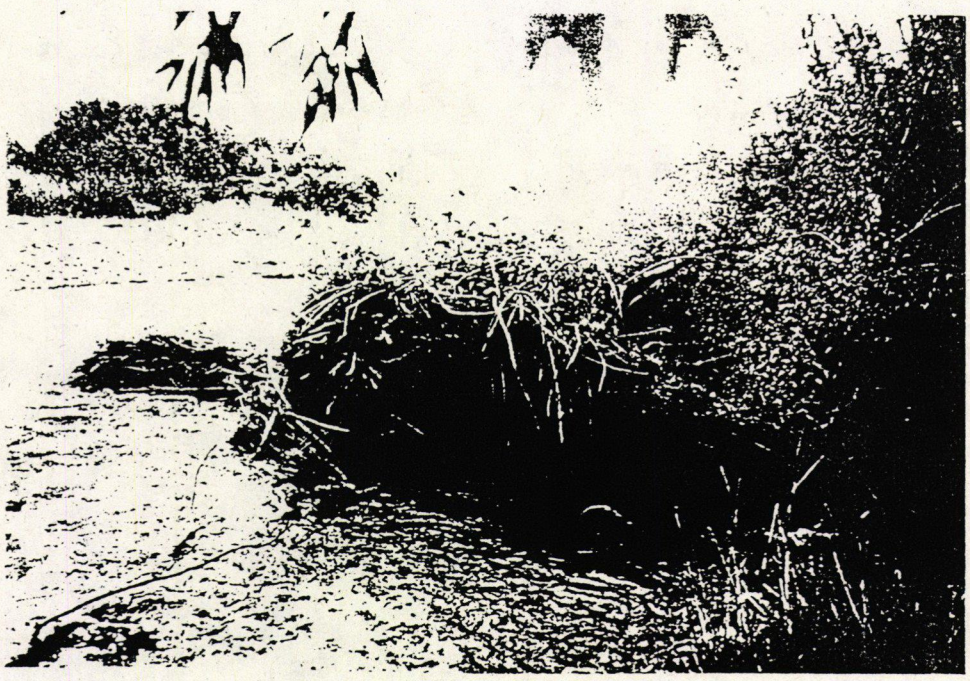
6.3.2 Range of willow behaviour

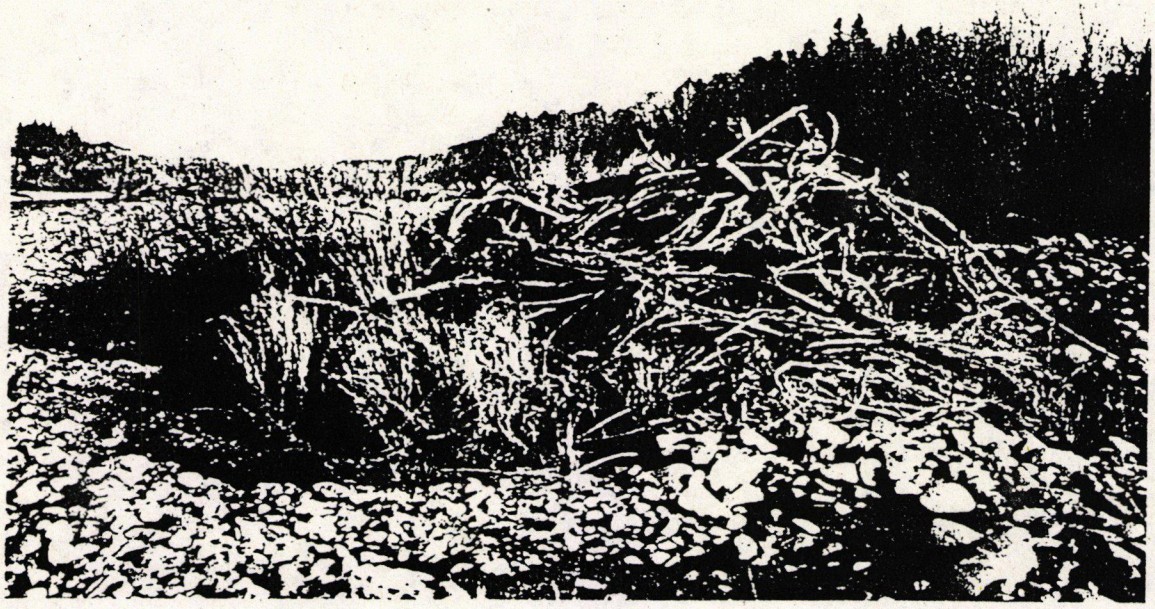
Differing habits of willows can be directly related to their location on different geomorphic units. The main observed form of willows in this section is an upright tree with numerous stems coppicing from the base. These multi-stemmed willows are mainly located on alluvial flats or bar platforms.

Willows located on chute channel units and channel marginal units were mostly up-ended, with the root-base at the upstream end and branches directed downstream. It is assumed that these willows were progressively eroded and/or overturned in a flood event, with the possibility of being carried downstream by flood flows. Active undermining of channel marginal willows is shown in Plates 6.3-3 and 6.3-4. Some overturned willows have upright regrowth growing from the original branches of the tree. Scour holes were frequently observed around the root-base and on the channel side of the overturned tree, and often on the non-channel side, as shown in 6.3-5 and 6.3-6.

Also observed was the partial or almost complete burial of overturned trees. Buried willows are located further away from the present channel, usually on the alluvial flats. As many of the multi-stemmed upright trees









observed on alluvial flats and bar platform units are overturned trees that have been completely buried by sediment, only ages of the regrowth can be determined. This phenomenon was observed by Sigafoos (1964), who used the technique of dating the regrowth to determine the year of burial in large flood events.

Erosion around the bases of these willows exposes a dense mat of fibrous roots, as shown in Plate 6.3-1. These roots trap fine sediment and can aid in the process of bank accretion. As well as fibrous roots willows also have tap roots to anchor the tree to slopes.

Vegetation, usually grasses, gorse and broom, typically grow in the lee of overturned trees. This zone is protected by the tree from the main flow. Willows growing on alluvial flat units are often associated with dense stands of gorse and broom. Mature willows tend to shade out all vegetation in their immediate vicinity, and are easily scoured around the bases.

6.3.3 Relation to flood history

Establishment dates of willows on the geomorphic units indicates willows colonised fluvial landforms after distinct flood events. Analysis was made of the hydrology data and the rainfall data from The Plains Station, to determine the dates of these flood events.

Willow establishment can be related to major events that occurred on March 7-10 1954, February 22-24 1958, May 16-23 1965, September 1969, September 8-9 1972, March 1975, May 31 1978, August 26 1980, January 13 1983 and January 27 1984. These events are well-spaced, indicating that willows have gradually increased in number and area since their introduction in 1950.

CHAPTER SEVEN - INTERPRETATION OF THE ROLE OF WILLOWS IN CHANNEL ADJUSTMENT

7.1 SUMMARY OF INTERACTIONS

7.1.1 Role of willows in bank processes

At sites where the willow growth on banks is dense enough, channel capacity is reduced significantly. Reduced channel capacity has resulted in two interdependent changes on the Mararoa River. The first is to promote abandonment of smaller channels and create willow swamps, as was observed at Site 2. Channel abandonment results in the concentration of flow into fewer channels, leading to the progressive degradation and scour of these channels.

Decreased channel capacity is also potentially regained by the flooding and erosion of the adjacent floodplain. Frequent flooding of adjacent farmland was reported by M. Barker, S. Chartres, D, MacDonald, and H. MacDonald, who have properties adjoining the river. Substantial damage to fences and paddocks occurs on a regular basis along this reach of the river. The potential for channel avulsion, and the trapping of the river on the floodplain behind the willow plantings, is also significantly increased.

Furthermore, progressive erosion of vegetated banks has resulted in the frequent toppling of mature trees. This has contributed to further destabilisation as the extensive root system of the willow causes large chunks of the bank to fail, shown in Plate 6.3-4. This leaves the exposed bank open to further erosion. Willows can also increase instability on opposite banks, and upstream and downstream of dense vegetation. Channel widening results from bank failure along degraded reaches.

TABLE 7.1-1

Summary of willow and river channel morpho-dynamics

FLUVIAL PROCESSES	WILLOW-RELATED PROCESSES	MORPHOLOGIC RESPONSE OF THE MARAROA RIVER
Bank processes	Bank accretion	Bank stability. Reduced channel capacity. Leads to channel abandonment, creation of willow swamps, concentration of flow into fewer channels, and localised flooding.
	Bank stabilisation	Defection of flow onto opposite bank, and erosion of bank. Increased instability upstream and downstream of stabilised bank.
	Surcharge weight of willows	Reduction of bank stability.
	Toppling of mature willows	Destabilisation of bank.
Flow processes	Vegetated banks	Increased channel roughness. Flow resistance.
	Toppled willows	Flow turbulence Deflection of flow onto banks. Log jams and debris constrictions. Mid-channel bar formation.
Bar forms	Debris on bars	Trapping of sediment. Growth of bars.
	Stablisation of bar platforms	Increased area of alluival flats. Decreased area of active bar surfaces.
	Blocking of chute channels	Channel abandonment.
	Scour around willows	Initiation of chute channels.

7.1.2 Role of willows in flow processes

Toppling of mature trees causes flow to divert around the obstruction. This results in flow turbulence and disruption to the flow thalweg. If the channel is small these toppled willows can form log jams and debris constrictions. Blocking of channels can occur, with the result of channel abandonment and diversion of flow.

When the channel is larger the toppled willow can become a mid-channel willow, as shown in 6.3-2. In low flows sediment and debris can accumulate in the lee of the willow, resulting in the formation of mid-channel bars.

7.1.3 Role of willows in bar forms

Willows influence and are influenced by the distribution of geomorphic units on bar surfaces. Juvenile willows are only located on bar platform units, as this is where willow debris is deposited by waning flood flows. As these willows establish they trap sediment and stabilise the bar platform. Erosive effectiveness of flood flows is reduced by the willows so that bar platforms eventually develop into alluvial flat units. The area of active bar surface is, therefore, reduced by the encroachment of willows.

Willows can also control the distribution of chute channels, which in turn controls the spatial pattern of geomorphic units on bar surfaces. Overturned willows can influence the location of chute channels as scour around the willow can develop into a chute. Willows can also block off the head of a chute channel, causing channel abandonment.

Channel abandonment occurs on a wider scale when a dense stand of willows is located adjacent to the main channel. This occurred at Site 6 where a mature stand of willows at the upstream end of tight meander caused

deflection of flow into a smaller channel. This smaller channel eventually became the main channel and the meander was abandoned.

7.2 TEMPORAL AND SPATIAL SCALES OF INTERACTION

Willows appear to be moving progressively downstream along this reach in response to large flood events. Willows are densest and oldest at the beginning of the reach, decreasing in age and density downstream. Beyond Fern Hill, at the end of the reach, there are still extensive unvegetated bar surfaces and willows are not as large.

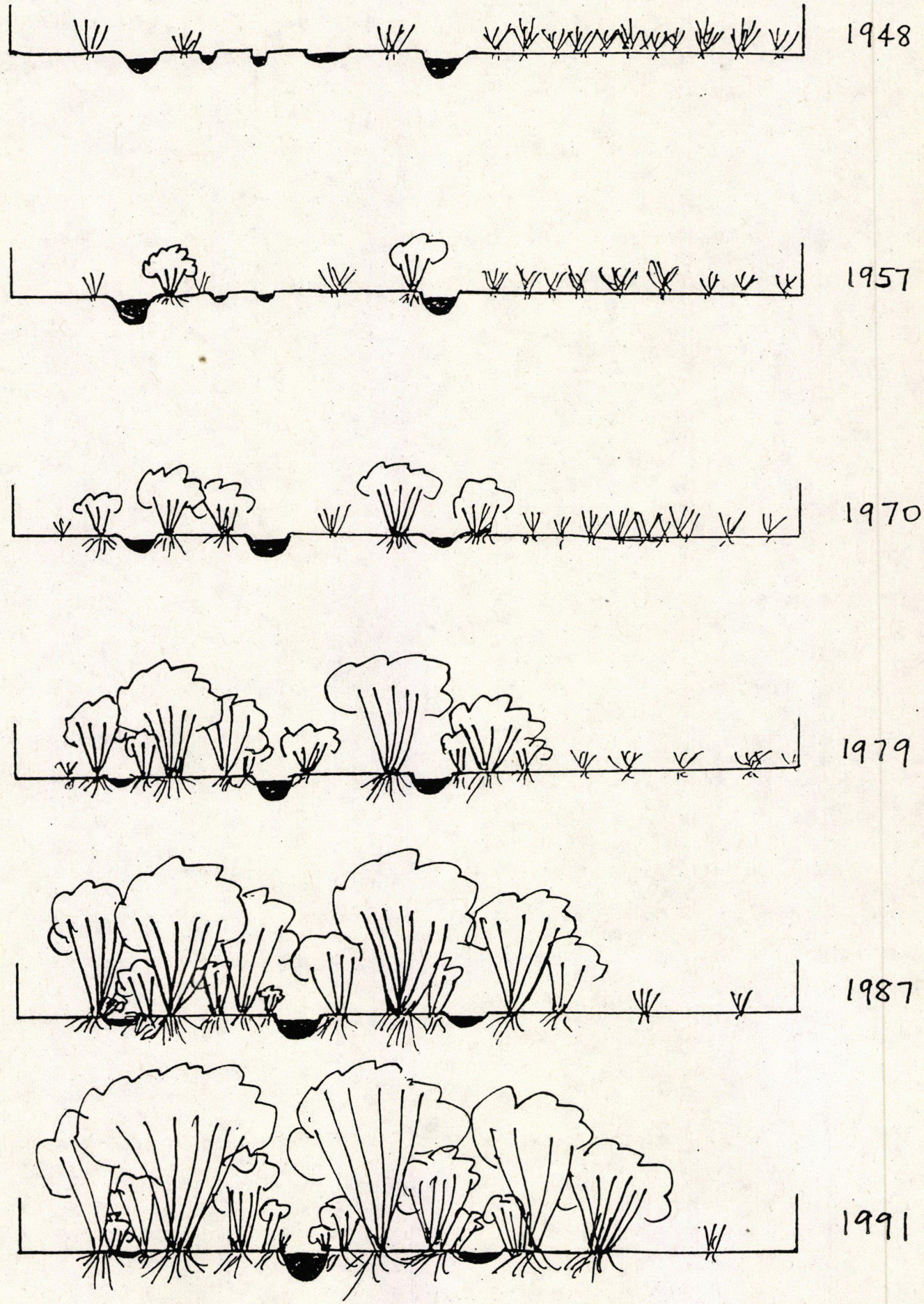
Establishment dates of willows can be related to flood events in 1954, 1958, 1965, 1969, 1972, 1975, 1978, 1980 and 1984. These are well-spaced indicating a constant rate of willow spread downstream. This is confirmed by the aerial photographs, which show a progressive spread of willows from their site of introduction. From this information a stylised sequence of channel change along the Mararoa River in this reach was developed, illustrated in Figure 7.2-1.

The first cross-section in Figure 7.2-1 shows the river in 1948 when there were no willows in the channel zone. By 1957 willows had sparsely populated bar surfaces, spreading halfway down the reach. Tree ring dating shows that willows had established on Sites 2 and 3 after a flood event in 1954.

Willows had established all along this reach by 1970. Willows continued to increase in number and area at Sites 1, 2 and 3 after flood events in 1958, 1965 and 1969. Willow dates on Site 4, 5 and 6 show they were probably colonised by willows after a large flood event in 1969.

Large flood events in 1972, 1975 and 1978 demonstrate that the period

TABLE 7.2-1
Stylised sequence of channel change, 1948-1991



between the 1970 run and the 1979 run was a time of vigorous spread and growth of willows. Channel abandonment appears to be the main mechanism in channel shifting in this period. Abandoned channels typically created willow swamps.

Between 1979 and 1987 willows continued to colonise bar surfaces so that there were few active bar surfaces by 1987, especially at the upstream end of the reach. The second and third largest floods in the hydrologic data occurred in 1980 and 1984, respectively, resulting in the rapid spread of willows.

The 1991 cross-section shows a densely vegetated channel zone. A few months before the photos were taken the largest flood in the hydrologic record occurred. This resulted in the overturning of many mature willows, causing bank instability and flow obstruction.

7.3 CONTROLS ON WILLOW AND RIVER CHANNEL MORPHO-DYNAMICS

The highly fluctuating nature of discharge on the Mararoa River is an important control on willow and river channel morpho-dynamics. Flows dictate the progression of willows downstream and their rate of establishment. Spread of willow relies on high flows to carry willow branches to bar surfaces. Willow branches are deposited on bar platforms in waning flow stages, and willows establish on these surfaces during times of low flow.

Variability in discharge influenced channel widths and number of channels. Hydrology and rainfall data show that the photos taken in 1970 and 1991 were in times of low flow, and 1987 in a high flow stage. The 1957 photo as at a low to average flow stage. Details on the discharge stage for the 1979

and 1948 photos are not known. This resulted in the fluctuation of channel widths and number of channels, as shown by the channel cross-sections.

Amount and size of sediment are also important controls on willow and river channel morpho-dynamics. Abundant sediment derives from glacial outwash terraces and the surrounding mountain ranges. Sediment ranges in size from sands to coarse gravels. These variables determine the morphology of channel and the floodplain. Stream power has been reduced by the encroachment of willows in the channelised zone and increased channel roughness. This has resulted in the storage of sediment once actively moved through the river system.

Geology acts as a control on channel adjustment through its influence on bed and bank material composition. Bedrock constraints have little impact on channel morphology in this reach, although terraces have imposed some restriction on floodplain extent. Climate regulates the river through rainfall duration, magnitude and intensity. No short-term patterns or long-term trends in the climatic variables were observed.

Human impact has modified the Mararoa catchment significantly. Changes in land use that have occurred since European settlement include clearance of forests, burning of tussockland, drainage of swamps, introduction of animals, building of roads and bridges, and establishment of agricultural activities have had indirect and complex consequences on river morphology. For example, The Key Bridge places a structural control on sediment availability by accentuating the aggradation of sediment and delaying the transport of sediment downstream. The role of human activities in controlling willow and river channel morpho-dynamics can be difficult to quantify.

CHAPTER EIGHT - CONCLUSIONS

The Mararoa River is located in Western Southland on the South Island of New Zealand. The river has a coarse, non-cohesive bed-load, a fluctuating flow regime, and it flows through steep, formerly glaciated terrain. Abundant sediment derives from a series of actively eroding glacial outwash terraces along the course of the modern river. The present character of the Mararoa River is an artefact of regional history, reflecting the antecedent controls of tectonic uplift and glacial deposits on channel condition.

From personal accounts and photographs it is known that the Mararoa River was originally a braided river with active bars and a floodplain vegetated by tussock. With the introduction of willows into the fluvial environment in 1950, the Mararoa River adjusted over the next 40 years to a wandering gravel-bed style. Examination of the role of willows in this change in channel planform was the focus of this study.

Willow/river interactions were examined along one reach of the river, from The Key Bridge to Fern Hill. An integrative approach to field work and data collection was taken in this study, incorporating aerial photograph interpretation with analysis of geomorphic units on bar surfaces and tree ring dating of willows. This combination of techniques focussed on willow and river channel morpho-dynamics in the period 1948 to 1993.

The use of photogrammetry involved the analysis of aerial photographs from 1948, 1957, 1970, 1979, 1987 and 1991. The 1948 run predates the introduction of willows and shows a treeless floodplain. The river has 5-6 channels, a sinuosity of 1.1, and unstable channels. This is evidenced by extensive gravel surfaces and the abundance of bar features.

Aerial photos from subsequent years show the stabilisation of these active bars by willow growth and their conversion to stable, densely vegetated islands. The channel zone was progressively reduced by the encroaching vegetation, with the alluvial flats vegetated by dense stands of willow, gorse and broom. By 1991 there are 2-3 active channels with one primary channel, channel sinuosity of 1.35, and irregular channel stability.
A prominent channelised zone is evident within a series of broad sweeping bends. Areas of instability are the result of channel incision and widening, and formation of mid-channel and point bar features. It appears that sediment is not as effectively moving through this reach as compared with upstream reaches.

Field analysis addressed four central questions of where, how, when and why do willows and rivers interact. The question of 'where' addressed whether there are any patterns in the location of willows on bar surfaces in relation to geomorphic units. Five geomorphic units were recognised, including alluvial flats, chute channels, bar platforms, ridges and channel marginal units. Willows were found to be located almost exclusively on alluvial flats and bar platform units. Chute channel, ridge and channel marginal units were mostly unvegetated apart from willow debris and the occasional overturned willow.

The question of 'how' aimed to outline the range of willow behaviour that occurs along this reach of the river. This was achieved through the examination of form/process associations on bar surfaces. Geomorphic units were found to influence the distribution of the willows, and in turn the willows influenced the distribution of the units. Willow branches were washed downstream and were deposited on bar platforms in the waning flow

stages of floods. Willows were able to establish on and stabilise these units. Branches deposited on other units were unlikely to establish due to the shading effects of mature willows on alluvial flats, and the regular inundation and reworking of chute channels, ridges and channel marginal units.

Willows were found to control the distribution of chute channels on bar surfaces. Blocking of chute channels by willow debris causes the abandonment of these channels, and scour around channel marginal willows causes the initiation of chute channel. As chute channels control the spatial distribution of geomorphic units, willows play an important role in overall unit distribution.

Willows were also found to influence the bank processes of bank accretion, stabilisation and failure, the flow processes of flow resistance, turbulence and obstruction, and the sedimentation of bars.

The third question analysed the time period in which river/willow interactions have occurred. This allowed the development of a stylised sequence of channel changes since 1948 based on aerial photograph interpretation and willow dates.

Willows were found to establish response to distinct flood events. Analysis of tree cores revealed that these flood events were well-spaced, indicating that willows moved progressively downstream.

The final question examines the controls on willow and river morpho-dynamics. The main control was the highly fluctuating discharge regime. Availability of sediment and human modifications to the catchment were also important variables in controlling willow/river interactions.

These findings have important consequences for river management, especially in the use of vegetation in river management. Implications for management of the Mararoa River are discussed in Chapter 9.

CHAPTER NINE - IMPLICATIONS FOR RIVER MANAGEMENT

8.1 MANAGEMENT OPTIONS

For effective management of the Mararoa River the wide and often conflicting uses of the river must be re-examined. Current uses of the river and its floodplain include farming, gravel extraction, supply of water for hydro-power, angling, canoeing and other recreational activities. The implementation of a management scheme is essential so that these uses can be balanced without detrimentally effecting the river.

A cost/benefit analysis of all management options is a necessary step. Options for management of the Mararoa River include:

* Doing nothing - A "leave it alone" approach. The benefits of willow growth include increased value to trout fisheries, relative stability of the channel zone and greater area of floodplain to use for grazing purposes.

However, the economic costs of uncontrolled growth of willows include significant disruption to the river system, increased potential for damage to The Key Bridge, flooding of adjacent farms, and the possibility of disruption to the Lake Manapouri Hydro Scheme. Present conditions have the potential to further deteriorate so that the willows completely choke the channel zone, intensifying flooding problems. This has occurred on the Tauweru River in the North Island, New Zealand, where flood costs are crippling farmers (Annabell, 1993). A non-action approach now will eventually necessitate the construction of expensive flood protection works in the longer-term.

* Maintenance of willows - To achieve a clear channel. This would maintain channel capacity so high flows are able to be transported effectively. Tight control on willow growth is required, involving expensive ongoing maintenance of willows.

* Complete removal of willows - To achieve a completely clear floodway through the riparian zone so flood flows are unimpeded. Elimination of the willows would remove the problem source so that the river is allowed to rehabilitate itself (Gordon et.al., 1992). This would typically involve the use of herbicides to kill the vegetation and bulldozers to clear the debris. Other methods include burning, plowing, discing and use of a root rake (Graf, 1980). Initial clearing effort would also need substantial follow-up work to keep the channel clear.

Clearing the river of the willows could result in severe disruption to stream and terrestrial ecosystems. Removal would eliminate the stabilising influence on banks and promote the rapid removal of the stored sediment from the catchment. Gorse and broom would quickly colonise the areas left bare by the removal of willows (Green et.al., 1989). Removal of willows also reduces cover for birds and fish, and could lead to a significant decrease in the trout populations (Latta, 1974).

* Restoration to original conditions - To return the riparian zone to its natural vegetation of tussock. Tussock is adapted to local conditions and utilised by local wildlife.

Restoration is a long-term goal which has many costs involved. Restoration might not be feasible on the Mararoa as disturbance to the natural state has been severe. Recovery of a severely degraded river to its natural and morphological state can also be very slow.

Weighing the costs against the benefits of each option shows that there is no straight-forward answer to the management problems of the Mararoa River. A non-action approach, while the least expensive option in the short-term, may be the costly option in the long-term. Maintenance of willows requires expensive ongoing work and the preservation of an artificially created riparian environment. Elimination of the willow from the channel zone would increase channel capacity, but the trout population would be reduced. Native vegetation is slow to colonise banks and bars, compared to willows, so that restoration to original conditions could be an extremely slow process.

Management of the Mararoa River, therefore, faces a choice between maintaining an artificially created environment with some benefits, or attempt to restore more natural conditions with different benefits. If flood control is a main consideration in the management of the riparian zone then it seems some sort of channel clearing and maintenance is inevitable.

8.2 RECOMMENDATIONS FOR RIVER MANAGEMENT

* Routine maintenance to make sure that growth of riparian vegetation is controlled and channels are kept clear.

* Further introductions of willow species, especially crack willow, into river systems should not occur until the uncertainty as to their full ecological and morphological impact is resolved. Investigation should be made of the use of native species in river training, and bank protection works, in preference to exotic species such as willows.

* Long-term monitoring of river systems is necessary to provide data on the mechanisms of channel adjustments in response to vegetation. The impacts of human activities on river morphology also need to be monitored. Findings need to be used as an input into ongoing river works.

* The design of river management works based on individual solutions for each river and each reach. Rivers reflect a complex combination of 'styles' and forms, as was found on the Mararoa River. There must also be recognition of the highly dynamic and unstable nature of rivers. The engineering tendency to impose a universal and simplistic solution to all problems must be avoided.

* As noted by Gordon et.al. (1992), river 'improvements' should not be used as a substitute for dealing with more complex causes of stream degradation such as deforestation, overgrazing, road construction, urban developments and gravel/sand extraction. Ad-hoc river management must be replaced with an integrated catchment approach that combines suitable land management practices with effective river management. This would involve designing with nature rather than against it to assist in the recovery of sites. Long-term objectives must be incorporated into all management plan (O'Brien et.al., 1983; Gordon et.al., 1992)

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